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The Concept of Converted Electric Vehicle with Advanced Traction and Dynamic Performance and Environmental Safety Indicators: Theoretical Basis

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Abstract

Objectives: To produce effective technical solutions on the structure, composition and characteristics of propulsion systems of Electric Vehicles (EV) to be converted on the basis of conventional vehicles. **Methods/Statistical analysis:** The success of this work can be determined only in the framework of the full technological cycle for the conversion of conventional vehicles in electric vehicles. The conversion process shall be carried out according to a specialized procedure and be accompanied by a necessary implementation of specific criteria and guidelines to follow that will allow for the development of a truly effective in relation to consumer and performance properties of the electric vehicle. **Findings:** This article presents the results of the development of scientifically based concept for the design of the converted electric vehicles, including the methodology for calculating the key characteristics of the components of electrical traction systems, optimization criteria of operating characteristics of electric vehicles as well as the conversion principles of conversion. The aspects of the energy efficiency of propulsion systems are reviewed, while using multi-parameter characteristics, a qualitative analysis is made, including comparison of the optimal operating conditions of Internal Combustion Engines (ICE) of conventional vehicles and electric traction drive. The basic phases of conversion of vehicles to electric vehicles are laid down, which are defined in the framework of the basic phases and the necessary process operations. The results can serve as guidance material in the development of electric vehicles and assessment of electric vehicle performance at the design phase as well as contribute to a rational choice of propulsion system options at conversion. **Improvements/ Applications:** The indices, dependences, principles and provisions presented here build the basis of the concept of full technological cycle for the conversion and can be used to assess the characteristics of the convertible electric vehicle at the design stage, as well as contribute to a rational choice of powertrain parameters when converting.

Keywords: Conversion, Electric Vehicle, Electric Drive, Powertrain, Performance Characteristics, Traction System

1. Introduction

The numerous developments, the results of trial operation as well as the start of mass production of electric vehicles, confirm the benefits and the positive role of the latter in the saving of fuel resources and to improve the environmental performance of the Motor Transport System (MTS)[1]. The aggregate of measures aimed at the development, implementation and operation of environmentally friendly and energy-efficient vehicles, which include electric vehicles, is an essential condition for the improvement and development of motor transport system[2,3].The rationale of promising vehicles is not in doubt, especially now, when many countries, including the Russian Federation[4], intensify works for the production of mass-produced electric vehicles, the formation of charging station network and service of this type of transport.

Over the past few years, the share of hybrid vehicles has increased significantly in the total volume of vehicles imported in the Russian Federation (motor vehicle) and

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successfully took the appropriate niche that is dictated by the growing demand for this type of transport. At the same time, electric vehicles are gradually introduced to the domestic market. At the same time it should be noted that the production of new electric vehicle is expensive, both in intellectual and technical terms, since in this case, the economic component includes, in addition to costs for the design and manufacture of the Electric Propulsion System (EPS) and related components, the costs to solve aspects inherent in the development of the conventional vehicle. The latter is determined by the need to design and manufacture the chassis, transmission, running gear and the vehicle body itself. Against the background of these aspects it seems as reasonable to use existing developments - production of mass conventional vehicles with internal combustion engines. The conversion (retrofitting) of conventional vehicles in electric vehicles, in comparison with the development of electric vehicles "starting from scratch", is more cost-effective measures and, in addition, can serve as the basis for improving energy efficiency and environmental safety of vehicles in service and upgrading the existing vehicle fleet.

In this regard, the creation of cost-effective technical solutions for the structure, composition and characteristics of propulsion systems of converted electric vehicles to meet modern trends of development of this field and the relevant world level, it is an urgent task. The success of this work may be determined only in the framework of the full technological cycle for the conversion of conventional vehicles in electric vehicles.

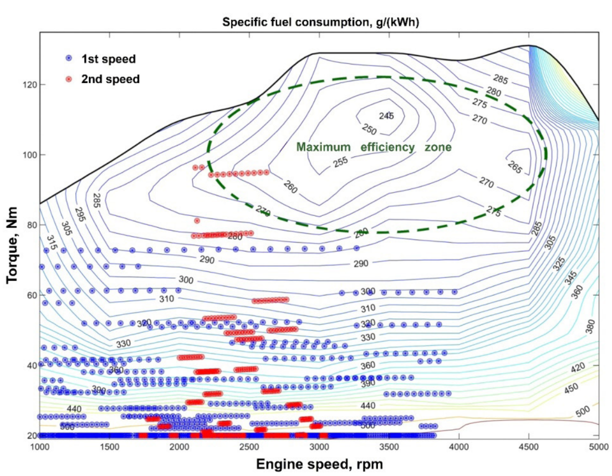

Figure 1. Multi-parameter characterization of gasoline ICE of car by value of specific fuel consumption.

The need for these works emphasizes the existing situation with the growth of prices for energy resources, coupled with environmental degradation, especially in large cities. A promising solution for the improvement of the MTS is a focus on the urban road transport for passenger services, including shuttle vehicles and taxis. The introduction of fuel-efficient and environmentally friendly propulsion systems in this area is feasible today and can certainly contribute to improving the air quality status in metropolitan areas and increase profitability of road transport enterprises.

2. Concept Headings

2.1 Parameter Fundamental for Concept of Conversion Full Technological Cycle

At the development of Electric Vehicles (EV) the significant factors affecting on parameters of the propulsion system and its structure, characteristics of EPS components are imposed requirements to performance of the developed vehicle, which in turn are caused by tasks during development. Among the performance indicators and electric vehicle characteristics are the following:

- purpose;
- speed and traction dynamic characteristics;
- energy efficiency;
- environmental performance;
- comfort;
- payload;
- electric range;
- charging time;
- reliability and safety indicators;
- compatibility with charging infrastructure;
- Economic indicators, including the cost of implementation and economic impact in the operation.

2.1.1 Purpose and Operating Conditions of EV

Among the listed above indicators, the ones to highlight include the purpose of the vehicle and the associated operating conditions, the requirements for speed and traction as well as the dynamic performance. The latter factors include the nature of electric driving mode, for example, the predominant use in urban or suburban traffic. The information on these indicators is the starting point for the formation of the initial decision on EPS structure, composition and the type of electric vehicle equipment in use.

Further subdivision of EV may be performed according to the purpose:

- for passenger services;
- cargo transportation;
- special purposes.

The intended use of electric vehicles is closely related to the operating conditions, according to which, the following application modes should be highlighted:

- predominant use in urban traffic;
- predominant use in a suburban traffic and driving on freeways;
- the combined use of urban and suburban driving conditions.

The emphasis on a predominant use in certain road operation conditions of the electric vehicle is required because this index of purpose determines the structure, composition and characteristics of the electric drive equipment, including traction and dynamic characteristics of the electric drive, electric, power and mass-dimensional parameters of the electric power source, and, consequently, such operating vehicle performance as the maximum speed and acceleration, range, energy and environmental efficiency.

The urban and suburban modes have significant differences in the parameters that are decisive in selecting the main component characteristics of the electric vehicle energy system. Included among these characteristics are:

- average and maximum driving speed;
- maximum acceleration;
- the total length of segments of idle run (standstill) in the cycle;
- the number of braking segments and the initial braking speed.

After review of the number of standardized testing driving cycles, taken in Europe and the United States, we can find a clear relationship between the average speed and the total length of idle run (standstills of motor vehicle). The suburban driving modes (e.g., HFEDS, US06, and EUDC) are characterized by higher average speed and small numbers of idle run segments, while urban traffic conditions (ECE, NYCC, J10-15) are characterized by indicators which are opposite to suburban indicators.

The low speed of motor vehicle and frequent stops are characteristic to urban traffic and busy roads. In such circumstances, the propulsion system of the conventional vehicle is mainly running at low load and at idle run mode, which adversely affect its fuel efficiency. The use of an electric drive on the vehicle can be a means to solve this problem through the exclusion of inefficient modes of operation of the Internal Combustion Engine (ICE). This fact is an important factor that determines the possibility of increasing the energy efficiency of motor vehicle and environmental safety of the latter when it is converted to electric vehicle.

2.1.2 Energy Efficiency of EV and Conventional Vehicles

To enable visualization of operating conditions of the ICE operating conditions at the conventional vehicles as well as modes of its effective operation, can use multi-parameter characterization. Figure 1 illustrates engine map on the specific fuel consumption of the car, which shows the operating points (a pair of torque values and rotation speed) corresponding to engine operation modes, when driving of conventional vehicle in the urban cycle (NYCC).

The illustrated characteristic clearly demonstrates a conventional ICE vehicle in urban driving conditions working at a high rate of specific fuel consumption modes, i.e., in conditions of low engine efficiency. At the same time, the zone of optimal specific fuel consumption (high efficiency zone) is not practically used.

A direct comparison of the effectiveness of the ICE vehicle and traction electric system of the electric vehicle can be done by comparing the efficiency values of the propulsion systems. Figure 2 shows such dependence - the efficiency of the rotation speed and the load of the ICE and traction motor[5].

Following the analysis of the above dependence, a conclusion can be made on the efficiency level of the conventional vehicle propulsion system and propulsion system of the electric vehicle, namely:

- Efficiency of the modern ICE does not exceed 35%, while its maximum values are achieved at high load conditions and the zone of maximum efficiency of the ICE is substantially limited.

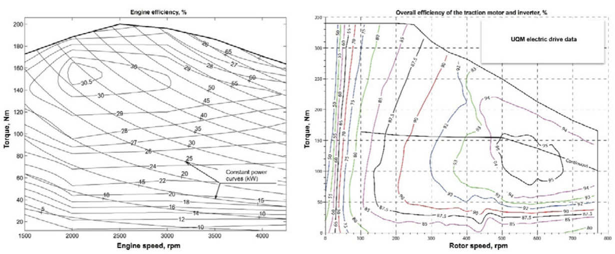

Figure 2. Dependence of efficiency of gasoline ICE of car and efficiency of traction electric drive[2] against rotation speed and torque.

- Efficiency of the propulsion system of electric vehicles (overall efficiency of the traction electric motor and a traction inverter) can reach 95%, while the effective operation zone of EPS, as against the ICE unlike much larger and includes external characteristic. This fact has the potential to improve traction and dynamic characteristics of the electric vehicle while maintaining a high efficiency of the propulsion system.
- Efficiency of the ICE at low load modes inherent to operation of motor vehicle in urban driving conditions is within a range of 0 ... 18% (including idle run), while a similar characteristic of the traction electric drive has a range 55 ... 90%, provided that the electric propulsion system excludes, by definition, operation of the traction electric motor at idle run (in the standstill mode of the vehicle).
- It should be also pointed to the fact that the energy efficiency of the vehicle's propulsion system is directly related to its environmental performance because fuel consumption of the ICE can be compared with the amount of toxic emissions.

Another factor that significantly affects the performance of energy and environmental efficiency of an electric vehicle is the use of regenerative braking energy. The greatest relative values of regenerative energy occur in the urban cycle due to the high frequency of braking modes. However, the driving cycles with higher average speeds also cause a significant potential for energy regeneration during braking, because high vehicle speed values lead to longer braking segments and significant power generated by traction motor generator.

Improvements in the environmental performance of the vehicles in use, as well as the possibility of saving flue, must be considered with regard to the actual conditions of predominant motion and purpose Thus, the use of electric vehicle transport newly developed and / or converted from conventional vehicles with ICEs will have maximum energy and environmental efficiency in cities with overloaded transport infrastructure. Thus, the average peak rate in localities with high motorization level is usually 20 km/h. The small loads on the propulsion system of electric vehicle in hindered urban traffic mode and low average speeds all allow optimizing the speed, traction, and dynamic characteristics of the EPS of electric vehicles.

The above stated data presents the main shortcomings of the operation of propulsion systems of motor vehicle on the basis of heat engines - low energy efficiency of ICEs and emissions of toxic substances directly in the place of vehicle operation. Simultaneously, the key features of motor vehicles with electric drives are presented, including the distinct advantage in respect to the efficiency of electric drives (even in low efficiency modes) in comparison with ICEs. A comparison of the advantages and disadvantages of the two different types of propulsion systems in motor vehicles with the ICE and with the EPS is evidence for the capability and efficiency of the conversion of the vehicle to an EV which have high levels of energy and environmental efficiency. This comparison is provided in Table 1.

2.1.3 Consumer Attributes of EV

The modern vehicles should meet not only basic characteristics of its functional purpose, environmental impact and energy efficiency requirements, but simultaneously specific requirements of customers. The statement is mainly due to the fact that, on the one hand, there is the problem of preservation of natural resources and improvement of the ecological environment, the implementation of existing and future environmental safety standards, which are mostly of little worry to the end user, and are the subject of attention exclusively of automakers, environmentalists and government. On the other hand, there are purely consumer attributes of the vehicle, which are the main subject of consideration by the buyers. With regard to electric vehicles, these attributes shall include traction and dynamic performance, maximum range, comfort and safety, and ease of use. Only comprehensive approach to these characteristics of electric vehicles can provide a truly effective development in all respects, its further development, implementation and operation.

Table 1. Comparison of key features of vehicle with ICE and electric vehicle within areas of improvement of MTS

Vehicle on the basis of ICE	Electric vehicle converted on the basis of vehicle with ICE
Low efficiency of conventional ICE vehicle, especially on those modes that are most commonly used in urban conditions and the associated problem of inefficient use of fuel resources	High efficiency of electric propulsion system, including those provided by: - overall efficiency of contactless electrical machine and an voltage inverter in range of 55 - 95% in modes, where the ICE operates with different efficiency 0 -18%; - smaller losses in mechanical transmission, caused by the absence of the traditional gearboxes, clutches and friction coupling devices.
In efficient braking of motor vehicle	Possibility of regeneration of electrical energy when electric vehicle is braking and replenishment of portion of electric energy spent on the driving and power supply of on-board electricity consumers
Environmental degradation, especially locally, due to the mass usage of motor vehicles, a high level of motorization, crowding the transport infrastructure	The use of environmentally friendly propulsion systems other than zero local emissions of pollutants, including pollution from fuel evaporation, use of fuels and lubricants
Presence of high proportion of vehicles in total volume of the existing vehicle fleet that do not meet the newly introduced and future standards for emissions of hazardous substances	Implementation of existing and future standards on the emissions of pollutants
The low indicator of possible improvement of motor vehicles in operation inorder to improve fuel efficiency and environmental performance	Ability to modify and improve the conventional (based on the ICE) vehicles when converting the latest in EV
-	Efficient use of non-renewable natural resources in power plants at the expense of their optimum loading in the night hours (charge of electric power source of electric vehicle during the period of the night tariff system for electricity)
-	Ability to use alternative (renewable) energy (wind, solar, water, etc.). This feature can be provided by the electric power system
Use of existing and ubiquitous fuel infrastructure (petrol stations)	Need for a dedicated charging infrastructure However, some of this disadvantage is compensated with equipping the EPS with on-board charger that is compatible with three-phase and single-phase consumer network

In terms of attractiveness for a potential owner of an electric vehicle there needs to be refinement of these indicators of electric vehicles. The traction and dynamic characteristics are maximum acceleration and speed, acceleration response, value of torque of the propulsion system as well as the dependence of these parameters against the driving speed. These parameters play a significant role in the choice of the vehicle by the end user, but from them essentially depends on electric power capacity and parameters of the electric propulsion system.

The maximum range of an electric vehicle is the distance that it can be overcome until final discharge of electric power source from being fully charged. It is an important parameter that has long held back large-scale use of EV and their production. Modern power sources can increase the average range of EV through the use of the latest achievements in the field of chemical power sources – battery cells with high specific capacity and power, and, in addition, which are characterized by small duration of charging regimes, which ultimately provides the convenience of using the electric vehicles.

As a factor that determines the electric power source characteristics (mainly, energy reserve), it is necessary to allocate the following performance indicator as a daily range of the vehicle. Thus, the results of the trial operation of EV in the Russian Federation show that a use of EV by the municipal services requires a daily range of each vehicle, which does not exceed 35 - 45 km. The results of similar studies abroad also suggest that the main portion of the daily range of the vehicle is relatively small and does not exceed 50 km. Distribution of ranges of vehicles under urban conditions shows that the probability of the need to overcome the required distance of the vehicle in excess of 100 km, is below 5%.

The operation of EV in the limited distance driving conditions, for example, the movement of personal electric vehicle on route "place of overnight stay - the place of work of owner," and vice versa, or the movement of municipal transport vehicles on a preset route, can be considered as a criterion for determining the optimized characteristics of the electric power source.

The comfort is a quality of electric vehicle is worth of special attention, because as compared to conventional vehicles based on ICEs, EPS of electric vehicle does not contain a source of intense heat as well as permanent mechanical drive of auxiliary equipment, including air conditioning cooling systems. A safety of electric vehicle operation shall be dedicated as a separate issue, which is caused by the presence in the electric propulsion system of the high-voltage electrical equipment, proper arrangement of its operation and regular monitoring for a state of its individual elements.

The EPS of electric vehicles includes expensive components, with a significant portion of the total cost of EPS falls on electric power source. Due to that, the above indicators of purpose of electric vehicle, the conditions of its operation and driving, traction characteristics are crucial and ultimately define a technical solution with regard of EPS and final cost of sale of the vehicle.

3. Method and Result

3.1 Parameters and Indicators of Electric Propulsion System

The introduction of fuel-efficient and environmentally friendly propulsion systems is feasible today and can certainly contribute to improving the air quality conditions in metropolitan areas and increase profitability of road transport enterprises.

The above aspects of the operating characteristics of the vehicle allow formulating the following basic parameters and indicators of EPS of convertible electric vehicle:

- In relation to the traction and dynamic characteristics:

1. Maximum capacity of traction electric motor.
2. Peak torque of electric motor.
3. Maximum rotational frequency of electric motor.
4. Dependence of the maximum torque of electric motor from rotational frequency.
5. Coefficient of traction and dynamic compliance of convertible electric vehicle with basic motor vehicle.
6. Length of maintenance regime of peak torque on electric motor shaft.
7. Maximum discharge rate of EPS.
8. Nominal voltage of electric power source.
9. Capacity of electric power source.
10. Maximum capacity of voltage inverter and the associated input and output currents and voltage.
11. Weight and dimensional values of electric propulsion system components.

- In respect of energy and environmental efficiency:

12. Type of used electric power source and traction electric motor.
13. EPS efficiency, including the efficiency of electric power source, efficiency of the power voltage inverter, the efficiency of the traction electric motor and mechanical transmission.
14. Method and algorithm for converting the steady voltage of electric power source.
15. Optimized use of electric energy of electric power source for electric power supply of the vehicle onboard systems.
16. Use of regeneration mode of electric power, when it's parking the vehicle.
17. Service life and number of charge-discharge cycles of electric power source.

- In relation to operational properties for the end-user:

18. Maximum range of an electric vehicle.
19. Duration of charge of electric power source.
20. Characteristics of high-voltage equipment of the heating system and cabin air conditioning system.
21. Safety of EPS design and assurance of nominal operating modes of electric power source.

The above parameters of the traction electric equipment system of the convertible electrical vehicle in aggregate are decisive for traction and dynamic performance and environmental performance of electric vehicle. The choice, definition and calculation of these characteristics are the initial stage of the implementation of the technological cycle for conversion of the vehicle to electric vehicle.

3.2 Conceptual Principles for Conversion of Motor Vehicle to Electric Vehicle

The performance of the electric vehicle, converted on the basis of the conventional vehicle with the ICE as well as the EPS parameters shall comply with basic design principles that build up the basis of the concept of the full technological cycle for the conversion. In this case as a base it is necessary to formulate the following basic principles of the conversion:

1. The principle to ensure the optimized composition and EPS characteristics in terms of a functional purpose and operating conditions of the vehicle use.
2. Principle to preserve traction and dynamic characteristics of the base motor vehicle.
3. Principle to preserve functions of standard on-board systems of the base motor vehicle.
4. Principle to preserve at maximum level of the payload of basic motor vehicle.
5. Principle to ensure a comfort and safe operation of the electric vehicle.

The basis of rational choice of propulsion systems of the EPS which determining the traction and dynamic performance can include the following principles:

A). Power of traction electric motor and the power inverter shall be equivalent and provide:
- with respect to electric motor: the required values of torque and rotation speed of driving wheels for the implementation of the vehicle control driving cycle as well as maximum speed and acceleration.
- With respect of electric power source and power voltage converter: implementing the maximum power required for electric motor operation in limiting modes (maximum speed and acceleration).

B). Maximum power of traction electric motor of the convertible electric vehicle shall be equivalent to the power of the dismantled ICE of the base motor vehicle.

C). A peak torque of the traction electric motor throughout the range of operating rotation speed shall be equally relates to the torque of external characteristics of standard ICE, convertible by speed-change gearbox. The basis of these requirements includes the principle of conservation of traction and dynamic characteristics of the base motor vehicle after the conversion.

D). A choice of maximum power of electric motor can be performed by traction and energy calculation of the vehicle with full weight, therewith:

$$P_{EM} \geq \frac{P_W}{\eta_T},$$

where P_{EM} is maximum power on the electric motor shaft; P_W is maximum required power on the driving wheels of the vehicle; η_T is efficiency of mechanical transmission.

Enabling the optimized choice of the characteristics of the traction electric machine as a key component of EPS that defines the traction and dynamic performance of the electric vehicle as well as compliance with the basic principles of the conversion with the use of the coefficient of traction and dynamic compliance of the convertible electric vehicle to the base motor vehicle k_{TDC}. This coefficient is a dimensionless value and is numerically equal to the ratio of definite integrals external mechanical characteristics of the traction electric machine (or the total external characteristic of several electric motors) and the standard propulsion system of the base motor vehicle:

$$k_{TDC} = \frac{\int_{n_0}^{n_{\max.}} M_{EM.\max} dn}{\int_{n_0}^{n_{\max.}} M_{VPS.\max} dn},$$

where $M_{EM.max}$ is the maximum torque of the traction motor-generator, Nm; $M_{VPS.max}$ is the maximum torque of propulsion system of base motor vehicle (torsion torque of ICE at output of gearbox), Nm; n is – rotational rate at input of the compensation gear of the vehicle, rpm.

The coefficient k_{TDC} can take the following values:

1) $k_{TDC} > 1$ It indicates an improvement in traction and dynamic characteristics of propulsion system of convertible electric vehicle in comparison with the base motor vehicle
2) $k_{TDC} < 1$ It indicates the decrease of traction and dynamic characteristics of propulsion system of the convertible electric vehicle in comparison with the base motor vehicle.
3) $k_{TDC} \sim 1$ the propulsion systems of electric vehicle and base motor vehicle are equivalent on its traction and dynamic characteristics.

The graphic sense of coefficient k_{TDC} is a ratio of zones (areas) of the maximum mechanical properties of traction electric motor against propulsion system of base motor vehicle. The zones of maximum mechanical characteristics of traction electric motor and propulsion system of the base motor vehicle as well as the mechanical characteristics of the propulsion system of base motor vehicle on different gears of speed-change gearbox are provided in Figure 3.

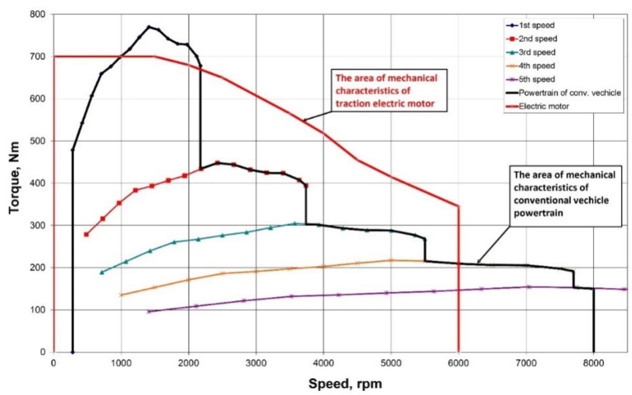

Figure 3. Graphic sense of coefficient of traction and dynamic compliance of convertible electric vehicle to base motor vehicle k_{TDC}.

E). A determination of the characteristics of the electric power source (battery cell) can be performed according to several conditions:

- In terms of required maximum range within the control cycle until battery discharge;
- Based on overload capacity of battery cell by current.

The required battery energy reserve required to ensure a motion of electric motor in the control cycle is determined in accordance with the expression

$$\mathrm{W}_{\mathrm{B.requir.}} = \mathrm{W}_{\mathrm{spec}} \cdot L_{requir.} \text{ ,Wh,}$$

where $L_{\mathrm{requir.}}$ is required range of electric motor, km; $W_{\mathrm{spec.}}$ is specific battery power consumption in control cycle, Wh/km:

$$\mathrm{W}_{\mathrm{spec.}} = \mathrm{W}_{\mathrm{B}} / L_C \text{ ;}$$

where W_{B} is battery power consumption in cycle, Wh; L_c is a range of driving cycle, km.

Its weight (kg) can be calculated for a known value of the battery specific energy:

$$\mathrm{m}_{\mathrm{bne}} = \mathrm{W}_{\mathrm{B.requir.}} / e_{spec} \text{ ;}$$

where $e_{\mathrm{spec.}}$ is battery specific energy, Wh/kg.

The rated capacity for a known value of the nominal voltage of the battery U_{bn}:

$$C_{bn} = W_{B.requir.} / U_{bn} \text{ .}$$

The minimum (required) capacity of the battery nominal energy, taking into account the overload capacity of battery cell by current:

$$C_b = \frac{P_{b.\max.}}{U_{bn} \cdot k_{CO}} \text{ ;}$$

where $P_{\mathrm{b.max.}}$ is maximum discharge capacity of the battery, W; U_{bn} is nominal voltage of the battery, B; k_{CO} is a coefficient of allowable overload by charge current. For modern lithium-ion batteries k_{co}=5…20.

To enable an assessment of the battery nominal capacity, taking into account the overload capacity by current and optimized level of battery charge, the following expression can be assumed:

$$C_{bn} = \frac{C_b}{\Delta\varepsilon_{opt}} \cdot 100 \text{ ;}$$

where $\Delta\varepsilon_{\mathrm{opt}}$ is a range of the optimum degree of battery charge (%) in the terms of battery life improvement and efficiency of the discharge-charging mode. The optimal battery level is equal to 60% can be accepted. Taking into account the limits of the charge degree during charging and discharging of ± 20%, the optimum range of charge degree is $\Delta\varepsilon_{\mathrm{opt}}$=40 %.

F). Assessment of electric vehicle payload at conversion

A necessary condition for an objective assessment of the energy efficiency of an electric vehicle is the analysis of the electrical energy consumption of the traction battery by criterion of performance of the same transport work. In other words, in determining the actual power consumption of the traction batteries of electric vehicle it shall be taken into account the rate of change of the vehicle payload after the conversion.

The payload of electric vehicle is the main operating characteristic, which represents the maximum weight of cargo transported at the same time and it shall meet the technical specifications of the base motor vehicle.

The calculation of payload of the electric motor is confined to the assessment of changes in the weight of the base vehicle when is converting. In this case, the initial data for the calculation are as follows:

- Payload of base vehicle G_v;
- Weight of dismantled equipment G_{de}
- Weight of installed equipment G_{ie}

Then, the expression[6] for determining the payload of the electric motor will have the form

$$G = G_v + G_{de} - G_{ie}.$$

The payload of electric vehicle can also be represented as the difference between the total weight of the vehicle G_{GVM} and own weight G_{CW}:

$$G = G_{GVM} - G_{CW}.$$

Once the payload is determined, the obtained results of power consumption of the traction battery of an electric vehicle shall be analyzed in terms of the implementation of the same transport work and adjusted. In this case, the transport work of the vehicle can be determined from the following expression

$$A = G \cdot L,$$

where Gisa payload of electric vehicle, t; L is range during implementation of transport work, km.

3.3 Full Technological Cycle Phases for Conversion of Conventional Vehicle to Electric Vehicle

In order to define the full technological cycle for the conversion of conventional vehicles to electric vehicles, first we must define "technology". A technology (from the ancient Greek τέχνη - art, skill, ability;Λόγος - thought, reason, method, production method) is an aggregate of methods, processes and materials used in any kind of business as well as the scientific description of methods of technical production.

Taking into consideration the specificity of the industrial sector and existing activities, the full process conversion cycle shall mean the ability to reproduce the totality and consistency of methods, technical solutions and the conversion process of initial (base) motor vehicle of conventional design (based on ICE) that allow to obtain a qualitatively changed vehicle - electric vehicle with preset parameters and characteristics, which is ready to be used on public roads.

Full production cycle for the conversion of vehicle design in the traditional electric car can be divided into stages of the conversion, each stage in the conversion of the individual steps, and each step on the stage carried out in the framework of work and production operations.

Full technological cycle for the conversion of conventional vehicle design in the electric vehicle can be divided into stages of the conversion, each stage can be divided into individual conversion phases and each phase on works carried out in the framework of this phase and production operations. At the same time the following phases shall be distinguished:

1. Design phase.
2. Phase for creation and preparation of EPS and related components (EPS).
3. Preparatory phase of base motor vehicle.
4. Phase of conversion.
5. Test phase of electric vehicle.
6. Certification phase.

The design phase is a set of phases and operations, the purpose of which is to develop technical solutions and design documentation, necessary for the production of electric propulsion system and conversion of motor vehicle to electric vehicle.

1. Design phases:

1.1. Assessment of feasibility of conversion of the base motor vehicle.

1.2. Determination of optimized structure, composition of EPS and electric vehicle on-board systems.

1.3. Elaboration of rational EPS layout on board of the electric vehicle.

1.4. Assessment of EPS parameters defining the traction and dynamic performance of the electric vehicle.

1.5. Determination of EPS component characteristics.

1.6. Assessment of unlade weight and payload of the electric vehicle.

1.7. Development of design documentation for EPS and components of the electric vehicle equipment to be installed and placed.

2. Phase for creation and preparation of EPS is a set of phases and operations, the purpose of which is to manufacture, test and preparation to install on the vehicle the EPS and on-board support systems.

Phases for creation and preparation of Electric Propulsion System:

2.1. Purchasing/manufacture of accessories for EPS of the electric vehicle, including:

- electric power source;

- traction motor-generator;
- voltage conversion and control system for traction motor-generator;
- power commutation devices;
- EPS controls and monitors;
- equipment for functioning the standard vehicle on-board systems;
- support equipment;
- propulsion structures for installation of traction electric machine on the vehicle;
- structural elements for installation and placement of EPS components.

2.2. Manufacturing the EPS stand-alone units.
2.3. Incoming inspection of purchased accessories.
2.4. Control over manufactured accessories and stand-alone units.
2.5. Installation of EPS components on functional test bench.
2.6. Connection of EPS components, including power and control electric circuits, hydraulic and pneumatic system components.
2.7. EPS bench comprehensive tests.
2.8. Adjustment of design documentation.
2.9. EPS refining to functional availability.
2.10. EPS dismantling from comprehensive test bench.
2.11. EPS preparation prior to installation on vehicle.
3. The preparatory phase of the base motor vehicle is an aggregate of steps and operations in the conversion cycle, aimed at dismantling the base vehicle, arrangement of space and places to install EPS components.

The preparatory phase of base motor vehicle includes the following steps:

3.1. Preliminary technical examination of the vehicle design by competent authorities.
3.2. Dismantling the standard powertrains of the base motor vehicle, including:

- ICE;
- speed-change gearbox;
- mechanical transmission elements.

3.3. Dismantling the controls and ICE operability assurance devices of the base motor vehicle, including:

- ICE (ICE) cooling system;
- oil lines;
- fuel system;
- exhaust system;
- control unit of ICE;
- electric wiring harness of ICE;
- other elements, which initial functional purpose excludes their use as a component of the convertible electric vehicle.

3.4. Installation of propulsion structures for traction electric motor(a single or several structures in function of EPS structure).
3.5. Assembly of structural elements to install and place EPS components on the motor vehicle.
4. The phase of conversion is an aggregate of steps and operations, aimed to install and connect electric propulsion systems and ancillary components of the electric vehicle.

The phase of conversion consists of the following steps:

4.1. Placement and installation on prepared base frames of EPS powertrains preferably in the listed below sequence:

- traction electric motor;
- electric power source modules;
- voltage conversion and control units of electric motor;
- power commutation devices;
- steady voltage converters of electric power source;
- ancillary high voltage units;
- EPS controls and monitors;
- equipment for functioning the standard vehicle on-board systems;
- ancillary electric equipment.

4.2. Placement and assembly of cooling system for EPS components, including:

- radiators;
- ventilating blowers;
- circulation pumps;
- connecting pipelines and branch pipes;
- fastening and sealing elements.

4.3. Electric connection of EPS propulsion components, including:

- electric motor;
- traction inverter;
- on-board system high voltage devices;
- EPS distribution panel;
- power commutation devices;
- electric power source.

4.4. Electric connection of EPS low-voltage devices.
4.5. Installation of equipment to ensure functioning of the standard vehicle systems.

4.6. Electric connection of equipment to ensure functioning of the standard vehicle systems.
4.7. Enabling the fuse elements of protection and emergency disconnect switch to power circuit of electric power source.
4.8. Pre-commissioning works and serviceability check of all systems of the electric vehicle.
5. Test phase is an aggregate of steps and operations for final inspection of serviceability and assurance of required characteristics of the electric vehicle.

The integral steps of test phase are as follows:
5.1. Tests of electric vehicle on chassis dynamometer system.
5.2. Road tests of electric vehicle.
6. Certification phase is an aggregate of steps and operations to ensure access of convertible electric vehicle to operation on public roads.

The certification phase includes the following steps:
6.1. Technical examination of motor vehicle design.
6.2. Issuance of the certificate of conformity of the motor vehicle with safety requirements.
6.3. Appropriate amendments to registration documents after conversion of motor vehicle.

4. Discussion

The building-up of cost-effective technical solutions for the structure, composition and characteristics of powertrains of the convertible EV that meet modern trends of development of this field and the relevant world level is an urgent task that can only be determined in the framework of full technological cycle for the conversion of conventional vehicles in electric vehicles.

These indices, dependences, principles and provisions build the basis of the concept of full technological cycle for the conversion and can be used to assess the characteristics of the convertible electric vehicle at the design stage, as well as contribute to a rational choice of powertrain parameters when converting.

At the development of electric vehicles, the essential factors affecting the performance of the powertrain and its structure are imposed performance requirements of the new vehicle, including preferential traffic conditions. The process of converting a conventional vehicle to electric vehicle shall be accompanied by a necessary implementation of specific criteria and guidelines to follow that will allow for the development of truly effective consumer and performance properties of the motor vehicle.

The results of the practical implementation of presented concepts in this article are reflected in the second part of this work, which describes the developed and produced experimental prototype of electric vehicle.

5. Conclusion

We have elaborated on the concept of full technological cycle for the conversion of conventional design vehicle into EV that meet the promising traction and dynamic characteristics and parameters of environmental safety. At the same time the full technological cycle of conversion is conditionally divided into conversion phases, each phase is divided in the individual steps, and each step is divided on work and production operations carried out in the framework of the phase.

The basic principles are set that build up the basis of this concept as well as the basis for a rational choice of powertrain features of the electric propulsion system. It was found that at the development of the electric motor, the significant factors affecting the performance of the powertrain and its structure are imposed performance requirements of the new motor vehicle, including preferential traffic conditions. In the case of converting a conventional design vehicle into an electric vehicle the key principle is the principle of conservation of traction and dynamic performance and standard on-board system functions of the base motor vehicle.

It was determined and justified an aggregate of basic parameters of the EPS of the convertible electric vehicle that define the traction and dynamic performance and environmental features of the latter. It has been established that the modern electric vehicle shall meet not only basic characteristics of its functional purpose, environmental impact and energy efficiency requirements, but at the same time satisfy the purely consumer requirements, which, however, depend essentially on the power capacity of electric vehicle and EPS parameters. To allow optimized choice of characteristics of traction electric motor as an EPS component, we have proposed a coefficient of traction and dynamic compliance of convertible electric vehicle with base motor vehicle that allows the quantitative assessment of efficiency of the accepted technical solutions and adherence of conversion guidelines.

The possibility of implementing a developed concept of a full technological cycle for conversion was justified under the directions of the improvement of motor transport system, reduce the adverse impact on the environment, the implementation of existing and future standards on emissions of harmful substances. It was demonstrated that the main shortcomings for functioning the vehicle propulsion systems based on heat engines - low energy efficiency of ICEs and emissions of toxic substances directly at the location of vehicle operation as well as features of the EV that reflect a clear advantage in terms of efficiency of the electric drive. A comparison of the advantages and disadvantages of the two different types of propulsion systems on the vehicle with ICE and vehicle with the EPS serves as evidence of the capabilities and efficiency of the conversion of motor vehicle in electric vehicles, characterized by high rates of energy and environmental efficiency.

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