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The concept of electric cross-country vehicle

Abstract: The article describes a conception of a off-road car, in which the self-ignition motor is planned to be replaced with a single or a group of electric motors. To implement the idea, it is planned to use a off-road Honker vehicle, produced in Poland. The choice has been made according to satisfactory cross-country properties of the vehicle, its reliability achieved by a simple design as well as positively user-rated performance in passing through the obstacles. The main aspect, still to be resolved, is the implementation of one electric motor to propel all wheels or four separate motors (each one for a single wheel). An important issue is the choice of a power supply, which can be a battery unit, recharged with a low power motor-generator.

The vehicle will be additionally equipped with an innovational telematics system with its main element – the set of sensors for toxic gases detection and a communication system. Measured data will be transmitted to the headquarters. After aggregating and processing the data, the current information will be sent to each of the vehicles. The article characterises main assumptions of this system.

Key words: full electric vehicle, power generator, telematics system

Koncepcja samochodu terenowego z napędem elektrycznym

Streszczenie: W artykule opisano koncepcję samochodu terenowego, w którym planowane jest zastąpienie silnika o zapłonie samoczynnym, silnikiem lub zespołem silników elektrycznych. W tym celu planowane jest wykorzystanie, produkowanego w Polsce, samochodu terenowego Honker. O wyborze platformy zdecydowały dobre właściwości terenowe samochodu, niezawodność spowodowana prostotą konstrukcji i pozytywnie oceniana przez użytkowników tzw. „dzielność w terenie”, oznaczająca wysoką zdolność do pokonywania przeszkód terenowych. Podstawowymi kwestiami, które pozostają do rozstrzygnięcia jest zastosowanie jednego silnika elektrycznego do napędu wszystkich kół – podczas jazdy terenowej, lub zastosowanie czterech silników (po jednym na każde koło). Ważnym aspektem jest wybór źródła zasilania, którym może być zespół akumulatorów, doładowywanych przy użyciu agregatu prądowórczego małej mocy.

Pojazd będzie dodatkowo wyposażony w innowacyjny system telematyczny. Jego głównym elementem będzie zestaw czujników do wykrywania niebezpiecznych gazów i system łączności. Dane pomiarowe będą transmitowane do centrali. Po zagregowaniu i przetworzeniu danych, aktualna zagregowana informacja będzie przesyłana do poszczególnych pojazdów. W artykule scharakteryzowano główne założenia tego systemu.

Słowa kluczowe: pojazd elektryczny, agregat prądowórczy, system telematyczny

1. Introduction

Throughout the last few years a significant growth of urban electric vehicles could be witnessed. In Poland, over a dozen of such cars were designed and implemented. Slowly, yet constantly, the cities have been provided with the recharging infrastructure. EU strongly supports such initiatives and provides hundreds of millions of euro on them annually. Thanks to this, a dynamic market development is being forecasted. The proposed project directly meets these expectations.

For a effective competition between the fuel-propelled and electric vehicles, each group has to provide the comparable power and range. The biggest challenge for the producers is designing:

- Highly efficient electric motors, having a significantly high power and torque ratio to their weight,
- Control systems, providing the maximized use of electric motors' advantages,
- High-capacity energy accumulation systems, capable of quick charge.

Honker vehicle have been produced in Poland since 1988 and undergone with constant improvements. According to producer's assumptions Honker is declared to be a technically simple and highly efficient car. A rally through the African desert was a good verification of its reliability. One of the vehicles successfully saved both the driver and passenger while a rollover. Price of the vehicles is adapted to their equipment and is highly competi-

tive to cars of similar class. It is also tens of percent than similar cross-country vehicles. Many versions of this vehicle were produced, i.e. passenger and van, and its main recipients are Polish Army and KGHM Polska Miedz (specialized vehicle designed for carriage of the miners).

The vehicle is equipped with both front and rear live axles, mounted on laminate-plate springs. The body depends on type of the vehicle.

To widen the recipient group, it is considered to design an innovative telematics system and electric drive system for aforementioned Honker vehicles.

Modular telematics systems will consist of three main elements:

- wireless sensor net equipped with dedicated for a specific recipient,
- a sensor unit, data acquisition devices and communication system,
- control for the traction system and battery charging with a capability of choosing different work modes and strategies,
- integrated control system for vehicle equipment, including the traction system and LED panel giving information on battery status, expected range and proximity to the target (based on GPS system).

Mass-produced combustion engine will be replaced by a single or a group of electric motors in the project. As one of the possible options, it is considered to mount the PMSM (Permanent Magnet Synchronous Motor) motor. Traction system and electric equipment of the car will be powered by the batteries or/and a supercapacitor of a volume enabling to cover the distance desired by the customers.

It is also expected to use an motor-generator, in order to extend the range of the vehicle. It will be used to power the on-board electric motor/motors and to charge the batteries in case no stationary source of energy can be used. The strategies of energy consumption will be divided into two groups – maximization of traction system torque during the cross-country ride or maximization of vehicle's range. Among these strategies a possible choice of intermediary solutions will be possible – depending on user's needs. The motor-generator will be equipped with a dedicated exhaust system, designed in scope of the project and limiting the risk of causing a fire in the woods and meadows by lengthening the route of the exhaust, especially taking into the account the high temperature exhausts. The exhaust system will be also equipped with a heat exchanger, in order to heat the interior of the vehicle, as well as additionally cool the exhausts. On the end of this system, a spark absorber will be mounted according to the standards developed for such type of devices.

2. Motor and the transmission

It is a challenge to design the transmission in a electrically-propelled cross-country car. There are solutions that imply equipping the vehicle with one electric motor, connected by the clutch and gearbox with wheel drive (similar to traditional vehicles). A radically different option concerns using several electric motors, one motor per a wheel. There are also intermediary solutions implemented, i.e. one motor (electric or fuel-propelled) per an axle. Direct propulsions (e.g. 'TheWheel' system), compared to commonly used solutions have following benefits:

- Higher maneuverability of the vehicle,
- Minimization of moving transmission elements,
- Higher effectiveness of recuperative braking,
- Lower level of vibrations and noise,
- Usage of ABS system,

Unfortunately, such solution significantly complicates the traction control system and higher amount of electric motors causes higher risk of a breakdown.

Variety of electric motors, in terms of their construction, functioning and control is very high. There are two main groups of such motors: synchronous and asynchronous ones. The first ones are most popular electric motors. They are used in different types of machines and are distinctive for their simple but permanent construction. Constructed motors can produce the power ranging from promiles of kilowatt to a few megawatts. The electromotive force is created in the rotor when it is rotating with a speed different from the rotation speed of the stator's magnetic field - the rotation speed of the rotor is lower than the spin speed of the stator. In case an external torque causing the excession of magnetic field spin speed affects the rotor, the motor becomes a generator. Thank to this, a partial recovery of the energy provided to the motor and charge of the batteries while braking is possible.

Asynchronous motors can be divided into squirrel cage motors and ring motors. The main advantage of the ring construction is a capability of plugging the additional elements to the rotor winding, which increase the resistance, enable better starting and the regulation of motor's rotation speed. Nonetheless, ring motors were almost fully displaced by squirrel cage motors, which are characterized by simpler design. The change was possible according to up-to-date electronic control systems. Modern inverters enable a precise control of rotation speed and more optimal use of induction motors.

Three-phase induction motors were used in following electric vehicles: GM EV1 (maximum power 102kW, maximum range 240km), Tesla Roadster (maximum power 185kW, maximum range 352km), Smith Electric Vehicle Newton (maximum power 120kW, maximum range 160km)

), Think City (continuous power 37kW, maximum range 180km), Ford Connect EV (maximum power 55kW, maximum range 130km).

Regarding the synchronous motors, the speed of the rotor is synchronised with spin speed of stator's magnetic field. Magnetized rotor ranges itself in the axis of stator's magnetic field. Then, if a rotating magnetic field occurs on a stator (it is generated by applying the voltage on subsequent windings), the rotator continuously ranges itself in the axis of stator's field and rotates with the same speed. A characteristic feature of synchronous motors is maintaining of constant rotation speed, independently from mechanical load of the rotator (which does not exceed the maximum electromagnetic torque of the motor).

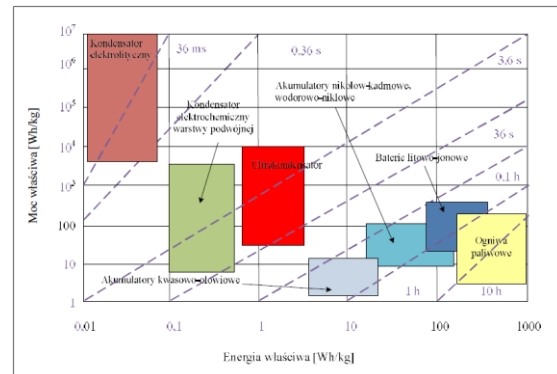
Technology development caused that recently, BLDC (Brush-Less Direct Current) and PMS (Permanent Magnet Synchronous) motors, in which the source for magnetic field of the rotator are the permanent magnets placed on it, have been applied in more and more places. They have been displacing induction motors thanks to higher precision of rotation speed regulation and the position of the motor shaft. They are characterized by high effectiveness, high torque compared to the current consumption, high power density, durability and reliability.

Synchronous motors are not, unfortunately, without the disadvantages. One of them is a lack of possibility for self-acting start after connecting the power to stator's windings. Significant frequency of changes of rotating magnetic field unables the start of rotator. A solution for this problem can be found by replacing electronic inverters, which enable a gradual windings' power frequency growth. The additional problem in typical synchronous motor control (using a sinusoidal or trapezoidal signal) is a necessity of feedback with the information on current motor shaft location. This causes a necessity of using the encoders, which complicates the motor design and therefore may unfavorably influence on its reliability and higher production costs. The solution for this situation may be usage of controlling the motor, which is based on estimating the position of the motor shaft using i.e. state estimators (Kalman filter), voltage measurement of the stator or the analysis of high-frequency signals provided to the stator.

Below, there are listed examples of the vehicles propelled with synchronous motors: Segway vehicle, Vectrix scooter (maximum power 20kW, power handling 9kW, range 109km), Audi A3 e-tron (maximum power 100kW, continuous power 60kW, maximum range 140km), Mitsubishi i-MiEV (maximum power 47kW, maximum range 180km), Nissan Leaf (maximum power 80kW, maximum range 160km), three-wheeled SAM Re-Volt (maximum power 11,6kW, maximum range 100km).

3. Power supply

Every electric car is equipped not only with a motor and control system, but also with in a power supply. Various solutions are known and spread on the market: using the batteries, photovoltaic cells, electric generators, fuel cells, supercapacitors. Following Ragone diagram shows the specific power in function of electrochemical power supply function. [1] (rys. 1).



Rys. 1. Ragone diagram for different electrochemical batteries

Źródło: [1]

An interesting solution that provides proper values of current instantaneous values as well as favorable price and capacity to weight ratio is the usage of parallel electrochemical batteries and supercapacitors. These power supplies vary considerably with discharge characteristics, which are flat for fuel-cells and hyperbolic for a capacitor.

In the proposed idea of a electric car it is implied that the torque of electric motors should be higher than 195Nm, which is a value reached by a production today Andoria diesel engine. According to this, the project concerns using the battery supply, supported with a supercapacitor, connected in parallel what will enable generating a high torque on the wheels of the vehicle. Thanks to this, the electric version of Honker will be characterized by improved cross-country performance and acceleration. Currently, urban electric vehicles are mostly equipped with lithium-polimer batteries. Such type of battery is not mechanically resistant, what becomes a source of possible danger – especially during the collision of such vehicle. That inconvenience is yet compensated by high energy density of such battery, which is measure for the capacity per one kilogram.

Batteries can be loaded with significant current values, yet their overload can cause an overheating or even a fire. According to this, it may necessary to monitor the temperature of the batteries installed in Honker vehicle. Additionally, a necessity for mounting a supplementary battery cooling system. Lithium-polymer batteries show practically no 'memory effect'. Therefore, they can be recharged at any moment without losing the capacity. A max-

imum amount of charging cycles is assumed at amount of 500.

Electrical vehicles are also equipped with lithium-ferric batteries, which have lower energy density than lithium-polymer batteries. However, they can be repeatedly charged and recharged – even a few thousand times during the whole usage period.

Supercapacitors can be used in parallel to main power supply to store the energy recovered from recuperative braking and, subsequently, provide the energy on peak demand. In the following project such solution is proposed, due to a capability of getting high instantaneous values of currents powering the motors. With a suitable choice of motor power value, this enables obtaining higher torques than in a combustion engine. Supercapacitors are a specific type of electrolytic capacitor having a capacity of several thousand farads. They have a short time of both charging and discharging. They also enable providing the power of around 10 kW per a kilogram of a such element.

A meaningful disadvantage of electric vehicles are strong magnetic fields generated by the motors. Yet, they are offset by covers which play a role of Faraday cage. The price of limiting the influence of magnetic field is a significant growth of car's weight.

4. Wireless sensor network

A wireless sensor network is a network made of different intelligent devices, named as nodes, which are placed on a monitored area in order to perform global tasks. A basic presumption of sensor network is a decentralized data acquisition and, subsequently, their digitization from the analog form. A node consists of sensors, made to monitor the parameters of physical phenomena, such as temperature, humidity, presence of a physical object, sound, vibrations, pressure, movement or pollution. Sensor networks consists of a high number of nodes which are distributed on a certain area and capable of data processing, storing them in the internal memory and communicating with other nodes in the network. The devices make up an ad-hoc network to share the collected data and send them to the provider and other network users. Sensor networks do not have a defined architecture. According to this, the nodes configure the network themselves and control its work. Virtually, a node provides three basic functions: measurement, data processing and communication, which are achieved using dedicated hardware, software and algorithms. Following implementations can be mentioned as an example of using sensor networks: measuring the values of physical quantities, detection of desired events, estimation of detected event parameters, and following the physical objects. A very important feature of wireless sensor networks is a capability to self-organize, provided automatically by the nodes, according to the dedicated algorithms. It

enables to minimize the energy consumption by power reduction in each of the nodes what subsequently leads to reduction of interference level in the network. Additionally, thanks to capability to self-organize, the networks is resistant to the damages and discharging the batteries in the nodes.

Sensor networks provide following advantages in comparison to other wireless solutions:

- physically small node sizes,
- no need of infrastructure, possibility of a quick establishment of the connection.
- energy efficiency achieved by implementing effective algorithms,
- self-organization of both network and routing,
- resistance to damage of the nodes,
- mobility, dynamic change of network topology thank to self-organization,
- simple scalability, possibility of adding additional nodes to a working network,
- minimization of human's participation in efficiency maintenance of the network,
- easiness of locating the nodes in the network,
- low costs.

5. Planned features of the vehicle and expected demand on a cross-country electric vehicle

The necessity of designing the electric cross-country vehicle results from a market demand for this type of product. It is especially welcome in activities that are strongly bind with keeping desired silence and specific fire protection from the vehicle's elements capable of providing the heat or sparks. Thank to this feature, the vehicle can be used in patrol activities, both civil and military. The additional advantage results from lack of exhaust emission, which both pollute the air and impact negatively on natural environment. This enables the Honker to access the areas of high environmental value, such as national parks and reserves. Aforementioned technical features help to specify the target group already in the stage of preliminary project assumptions.

Electrically-propelled Honker vehicle, additionally equipped with sensor network will be directed to the clients operating in cross-country conditions to protect the environment, repairs and removal of natural disaster effects as well organization working in scope of national security.

In Poland there are several types of authorities that have to include these factors while executing the tasks. The main target client of the end-product is The State Forests National Forest Holding together with Forest Guard, which consists of forest inspectorates workers, whose main tasks focus on detecting and fighting the crimes and offences made in

scope of forest wrecking. Forest Guard officers are in position to fine and sue the offenders to the court. The authority was established by a Forest Act on 28th September 1991. The officers perform their tasks using i.e. video and night vision devices and patrol vehicles, mainly cross-country vehicles and quads. Overall stock of The State Forests National Forest Holding consists of around 1300 vehicles, all of them fuel-propelled what constitutes a significant problem. This fact causes certain damages to natural environment, in which the foresters move around in scope of their everyday tasks, such as disturbance of wildlife due to a noise of a volume which is rare in the wild and negative influence of

exhaust gases for both fauna and flora. A significantly raised danger of forest patrols in fire hazard periods caused by low mulch humidity also has to be added – during such period entry to the forest is forbidden for all kinds of unauthorized vehicles, due to the possibility of starting a fire from the sparks coming out from the exhaust pipe. At the same time, The State Forests declare a need of protecting the forest areas against all widely understood pollution. Thanks to exploitation of electric cross-country Honker vehicles this postulate will be met also by minimizing the damage caused by forest authorities themselves.

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