Development of the solar electric bicycle and its test run on the Russian public roads

V Galushchak, A Soshinov, N Shevchenko*, O Elfimova and Yu Lebedeva

Kamyshin Technological Institute (branch) of Volgograd State Technical University, Kamyshin, Russian Federation

* E-mail: schewchenckonata1960@mail.ru

Abstract. The article presents the basic principles for development of electric bicycle transport in cities and towns of Russia. The technical characteristics of sun vehicle, developed by the authors are given. We describe the test run of passenger sun vehicle and three cycle hybrids along the route Volgograd - Sevastopol, with a length of 1350 km. We obtained the comparative characteristics between sun vehicle “TURIST” and industrial samples of electric bicycles. It was shown that solar electric vehicles can be successfully used on Russian public roads.

1. Introduction

In all developed countries, government programs are being implemented on environmentally friendly and economical transport. The search for ways to overcome the ecological crisis of road transport on the streets of Russian cities and on Russian roads leads researchers to the increasing use of electric transport [1]. In this case, the greatest interest is raised by electric transport with on-board supply of electricity consumed for movement [2,3]. Actually the electric car does not possess ecological cleanliness. Lithium for batteries, metal and other materials, without which it is impossible to create a car, are extracted from the earth in large quantities, which means that our planet continues to suffer from motorization. Plus, electricity is still produced by power plants that burn fuel, polluting the atmosphere. All these factors are minimized in electric bicycles [4]. Almost any bike can be made electric by installing an electric drive system (electric motor, battery, controller) on it [5]. Electric bike can be considered as an inexpensive and effective alternative for personal and corporate cars [6, 7]. Complete elimination of harmful emissions from combustion of motor fuel in transport is possible, for example, when switching to solar transport [8,9], which is a type of electric vehicle that receives electricity from on-board or stationary photovoltaic cells. The main source of energy in a solar vehicle is solar radiation, converted by technical systems into electrical energy, which is accumulated into the onboard storage system [10–12, 13].

2. Experimental sun vehicle “TURIST”

The works on solar electric transport have been carried out at the Kamyshin Technological Institute, the department "Power supply of industrial enterprises" for a number of years, and primarily the segment of solar bicycles (sun vehicles) is investigated [14]. In 2014-2015, the “DACHNIK” (vacationist) sun vehicle was designed, manufactured and tested (Figure 1). It is the pilot model of a line of three-wheeled solar freight electric bicycles intended for urban trips, recreational amusements...
in park areas and ecological bicycle tourism [15]. The sun vehicle is suitable for elderly people and people for whom for some reason a classic bicycle does not fit.

In 2015-2016, the “TURIST” (tourist) sun vehicle was developed and manufactured, which is a pilot model of a three-wheeled solar passenger bicycle line designed for short-distance, long-distance and ultra long-distance cycle tourism (Figure 2).

The ideology of this invention was based on the concept of a “legard” bike set. The driver of the sun vehicle is located on a soft ergonomic seat in the “half lying” position. The main source of energy is a solar battery. Solar energy is converted by the battery into electrical energy, which is accumulated in the onboard storage system. In the absence of solar radiation, the lithium-ion battery is a backup power source [16]. It is placed in a special battery cell between the rear wheels [17]. Also there is a common pedal drive. The front uncontrolled motor-wheel has a built-in asynchronous electric motor with a power of 1500 W and a nominal voltage of 36 V (Figure 3). The two rear wheels are steerable with an independent shock mount (Figure 4).

Sun vehicle "TURIST" is characterized by driving distance of 30 km at night or in the rain using the battery and 180 km in a sunny day. It can reach a maximum speed of 35 km/h and works well at a standard speed of 20 km/h, which is considered safe for bicycles and cyclists. The main characteristics of the sun vehicle "TURIST" are given in table 1.
Table 1. Characteristics of sun vehicle “TURIST”.

| Mechanics                  | Power generation                                      |
|----------------------------|-------------------------------------------------------|
| Motor-wheel PAINBOM        | Solar battery (Krasnogorsk, Russia)                   |
| Nominal capacity 1500 W   | Consists of 3 flexible modules MFS 100                |
| Nominal voltage 36 V       | Power generation capacity 300W                       |
| Efficiency ≥ 80%           | Photocell efficiency 22%                             |
| Maximum number of revolutions 600 rpm | Operating current 5.83 A                             |
| Wheel arrangement 3 wheel, controlled rear wheels | Voltage without load 21.1×3 = 63.3 V                |
| Duplicate gear Front wheel drive | Dimensions of solar battery 1060×530×2.8 mm         |
| Maximum speed 40 km/h      | Accumulator Li-Ion 36V 10Ah                          |
| Marching speed 20 km/h     | Accumulator mass 3.2 kg                              |
| Mass of sun vehicle 37 kg  | Maximum charge current 5 A                           |
| Dimensions, m 2.2×1.2×1.1 | Nominal/peak discharge current 15 A/45A              |

The requirements for power generation by solar battery were determined basing on aerodynamic forces of the incoming air resistance, rolling resistance, expected payload, travel speed and travel distance, as well as intensity of solar radiation.

3. Tests of the working model of “TURIST” sun vehicle

The research purposes are the following:

1. Testing the sun vehicle for the possibility of its use in long-distance and ultra-long distance bicycle tourism.
2. Adjustment of mechanical and electrical characteristics of the sun vehicle "TURIST".
3. A long route testing of behavior of various electric bicycles.
4. Comparison of the sun vehicle "TURIST" with industrial samples of electric bicycles.

The test run was conducted from 12 to 20 September 2016 along the route “Mamaev Kurgan, Volgograd - Sapun-mountain, Sevastopol”, with a length of 1350 km.

The stated task was to pass the specified distance using the sun vehicle operating solely on solar energy.

The route ran along the roads of the Volgograd and Rostov Regions, the Krasnodar Territory and the Republic of Crimea. The race started on the lower terrace of the Mamayev Kurgan memorial complex (Figure 5). The race finished at the diorama on Sapun Mountain in the city-hero of Sevastopol (Figure 6).

Climatic characteristics of the tests: autumn days, partly cloudy, no precipitations, wind of 3-5 m/s with gusts up to 7-12 m/s, air temperature +24 (+26) °C.

Besides the sun vehicle "TURIST", three bicycle hybrids participated in the tests: PATROL CARDAN 26, JAZZ 350W from Eltreco and LEISGER BASIC, provided by Lion-Tech, St. Petersburg. Comparison of technical characteristics of bicycle hybrids with sun vehicle “TURIST” is presented in Table 2.
Table 2. Comparison between technical characteristics of sun vehicle “TURIST” and bicycle hybrids.

| Technical characteristics | Eltreco PATROL CARDAN 26 | Eltreco JAZZ 350W | LEISGER BASIC MD5 Basic 27.5 | Sun vehicle TURIST |
|---------------------------|--------------------------|-----------------|-----------------------------|-------------------|
| Motor capacity            | 350 W                    | 350 W           | 350 W                       | 1500 W Motor-wheel |
| Gear type                 | Cardan                  | Chain           | Chain                       | Li-Ion            |
| Accumulator               | Li-on Samsung 36V 10.4Ah | Li-on Samsung 48V 11Ah | Li-on Samsung 36V 13Ah | Li-Ion 36V 10Ah |
| Maximum speed             | Not less than 25 km/h    | Not less than 25 km/h | Not less than 32 km/h | Not less than 35 km/h |
| Run without charging the battery | 45-60 km                | 45-60 km        | Up to 70 km                 | 30 km-at night 180 km-at day |
| Front brake               | Disc mechanical Shimano | Disc mechanical Artex 160 mm | Disc mechanical Tektro Novela 180 mm | No |
| Rear brake                | Roller Shimano          | Disc mechanical Artex 160 mm | Disc mechanical Tektro Novela 160 mm | 2 Disc mechanical brakes 160 mm |
| Driving                   | Combined use of the throttle stick and the Pass Control system | Using throttle stick | Using throttle stick | Combined use of the throttle stick and the Pass Control system |
| Net weight                | 25 kg 26”               | 27 kg 20”       | 22.5 kg 27.5”               | 37 kg 26” |
| Wheel diameter            |                          |                 |                             |                  |
| Load                      | 110 kg 26”              | 110 kg 20”      | 110 kg 27.5”                | 107 kg Front     |
| Gear                      | Front                   | Rear            | Rear                        | Rear             |
| Suspension                | Front with amortization | Front with amortization | Front with amortization | Rear with amortization |

Seven people participated in the tests: scientific supervisor, deputy supervisor, four pilots and machine operator.

Figure 5. Start of the sun vehicle race at the Mamayev Kurgan (Volgograd).

Figure 6. Finish of the sun vehicle race at the Sapun Mountain (Sevastopol).

Movement on public roads was carried out in a column: the head-car with orange flashing light, sun vehicles at a distance of 150–200 m behind it, three hybrid bicycles at a distance of 10–20 m and a trailing car with orange flashing light at a distance of 15–20 m from them.

The condition of the roads in the Rostov region and in the Krasnodar Territory on the route was good, in the Volgograd region and the Republic of Crimea it was satisfactory. Headwind is the main factor affecting the speed and range of the sun vehicle during daylight hours. In a presence of strong
head wind, it was possible to cover 110–120 km per day, and in a presence of side wind the maximum distance was 160–180 km. The average speed on the route was 20 km/h.

On bicycle hybrids, a large load fell on the back, neck and shoulders of pilots. Even trained cyclists started to hurt their muscles after several hours of travel. Sun vehicle does not have this disadvantage. Due to the comfortable lying position, the driver did not feel any tension in the arms and back. He did not have to hold his body, leaning on the steering wheel. All the weight was kept by a comfortable chair. Moreover, low landing prevents serious injuries from falling, as its height is small. Due to low raise and compact sleek design, air resistance is reduced by one third. This contributes to achievement of high speed and saves forces for acceleration.

A steep rise to Sapun-Mountain (about 40-60º) showed that the sun vehicle requires an electric motor with a power of about 5–6 kW. So, the rise was performed in the mode of the combined drive: the work of propulsion electric motor of 1.5 kW at full power with power supply from the onboard accumulation system and the work of pilot with a pedal drive.

In Alushta, the sun vehicle was presented in a poster presentation at the international forum “Innovative Directions of the Development of the Crimea” [18]. The decision of the forum was to recommend the enterprises of health resort and tourist business of the Crimea to consider the possibility of using the “DACHNIK” and “TURIST” sun vehicles in daily work [19].

4. Conclusions
1. During testing, the possibility of moving solar electric vehicles on Russian public roads was proved. The field tests proved the ability of sun vehicles to overcome distances of more than 1000 kilometers.

2. It was revealed that the maximum travel distance without recharging for the Russian sun vehicle “TURIST” is 180 km. The maximum speed was 40 km/h.

3. The characteristics of bicycle hybrids (table 2) show that the batteries are designed for 45-60 kilometers without charging. Practice has shown that without recharging, one can drive 80-85 km using JAZZ and 110-120 km using PATROL CARDAN and LEISGER BASIC.

PATROL CARDAN is a well-built and reliable bicycle hybrid equipped with a cardan drive, created for the difficult conditions of our country. However, at speeds above 25 km/h, the pilot's legs began to get very tired because the engine did not turn on.

JAZZ is a compact folding bicycle hybrid, equally comfortable both in the city and in country trips. Its main disadvantages are: poor running without an engine and lack of onboard computer

LEISGER BASIC is German bicycle hybrid of high assembly quality and well-thought-out European design and ergonomics. It is suitable for high speeds and long journeys. But it will be difficult to ride it in urban areas due to its large size.

4. To increase the competitive attractiveness of sun vehicles, it is necessary to develop appropriate infrastructure: bicycle lanes, parking places. Sun vehicles can also be considered as transportat for tourist trips.

References
[1] Hannan M A, Azidin F A and Mohamed A 2014 Hybrid electric vehicles and their challenges: A review, January Renewable and Sustainable Energy Reviews 29 135-50
[2] Timatkov V V 2015 Electric transport as part of the electric world. Facts and forecasts 48
[3] Titov D E and Galuschak V S 2012 Electric bicycles for Kamyshein, as a prototype of the system implementation of cycling in small cities. Scientific research and their practical application. The current state and ways of development (collection of works of SWorld materials of MNPK T 1) and A. G. Soshinov (Odessa) 1 95-100.
[4] Abagnale C and Cardone M 2015 Energy Procedia 81 618-27
[5] Abagnale C and Cardone M 2016 Design and Development of an Innovative E-Bike Energy Procedia 101 774-81
[6] Ji S, Cherry C R 2014 Electric bike sharing: simulation of user demand and system availability Journal of Cleaner Production 85 250-7
[7] Simsekoglu Ö and Klöckner C 2019 Factors related to the intention to buy an e-bike: A survey study from Norway January Transportation Research Part F: Traffic Psychology and Behaviour 60 573-81

[8] Popolov A S 1996 Solar transport (Moscow: Transport) 165

[9] Marsh G 2001 Solar travel: Harnessing the sun for transport Refocus 2(8) 30-32

[10] Galuschak V S and Soshinov A G 2014 Development of a Li-Ion battery of tubular type Actual problems of electronic instrument-making (APEP-2014: materials of the international scientific and technical conf.) 2 369-72.

[11] Galuschak V S and Bogdanov I V 2014 Li-ion batteries for electric vehicles Innovative technologies in training and production (materials of the IX All-Russian Scientific Practical Conference in 2 vols.) TV Kopeikina (Volgograd: VolgGTU) 1 40-2.

[12] Yerbaev Ye T, Galuschak V S, Soshinov A G, Artyukhov I A 2015 Patent for useful model KZ (13) U (11) No. 1390 MPK H01M 10/04 Li-ion battery of tubular type. Applicant and patent holder West Kazakhstan Agrarian and Technical University. named after Zhangir Khan - №2015/0036.2, announced 03/02/15; published 12.25.2015, bul.12

[13] Paudel A M and Kreutzmann P 2015 Design and performance analysis of a hybrid solar tricycle for a sustainable local commute Renewable and Sustainable Energy Reviews 41 473-82

[14] Galuschak V S, Soshinov A G, Karpenko O I, Karpizenkov A V, Fedorov A A 2008 Helio bicycle Patent No. 82640 Russian Federation MPK B60L8/00 applicant and patent holder GOU VPO Volgograd State Technical University No. 2008150039/22 declared. December 17, 2008; publ. 05/10/2009 Byul. №13.

[15] Titov D E and Galuschak V S 2011 Bicycle grid. Creative youth for the city of Kamyshein (materials of the V region. Scientific practical student conf. in 5 vols.) 4 95-7

[16] Mellino S and Petrillo A 2017 A Life Cycle Assessment of lithium battery and hydrogen-FC powered electricbicycles: Searching for cleaner solutions to urban mobility International Journal of Hydrogen Energy 42(3) 1830-40

[17] Galuschak V S, Soshinov A G, Atrashenko O S, Kopeikina T 2015 Solar photoelements or Stirling engine - realities and future of solar energy International Journal of Applied and Fundamental Research 9(3) 410-5

[18] Galuschak V S and Bogdanov I V 2016 Sun vehicles are a new type of transport for the tourist and holiday-resort business of the Crimea. Problems and prospects for the innovative development of the economy (materials XXI MNPK) 236-238

[19] Resolution of the Scientific Forum-XXI Interregional Scientific and Practical Conference 2016 “Problems and Prospects of Innovative Development of the Economy”(Crimea, Alushta)