Mechanics and Mechanical Engineering Vol. 21, No. 3 (2017) 513–522 © Lodz University of Technology

Evaluation of Traction parameters of Small Electric Vehicle

Przemysław ŁAZIŃSKI Department of Vehicles and Fundamentals of Machine Building Lodz University of Technology Żeromskiego 116, Łódź, Poland p.lazinski@wp.pl

> Received (16 June 2017) Revised (15 July 2017) Accepted (18 August 2017)

The modern automotive industry is looking for more efficient and environmentally friendly power sources for vehicles heading toward electric drives. The article presents the prototype of a small electric vehicle, which was developed in the Department of Vehicles and Fundamentals of Machine Building at Lodz University of Technology. This vehicle is equipped with an electric drive system by replacing the manufacturing combustion engine (SI), asynchronous electric motor with an electronic power converter. It describes the process of creating a mathematical model, numerical modeling and its solving. The results of tests carried out on the real vehicle and numerical research obtained from the numerical model were analyzed. Based on that there were presented conclusions of the numerical model and further working on the project and development of a prototype of the vehicle. The possibility of wireless power electricity of vehicle was considered.

Keywords: electric vehicle, prototype, hybrid, wireless transfer.

1. Introduction

For more than one hundred and twenty years the cars have been driven by piston engine with internal combustion. Since then, there has been a huge development of these constructions. Their efficiency has been increased and the power unit has been raised. Traction parameters of combustion engines have been improved, which nowadays can be almost arbitrarily modeled. Modern engines achieve more than 40% of maximum efficiency in power processing, but almost exclusively in steadystate conditions. In unsteady-state conditions the efficiency decreases. This decline causes a reduction of the overall efficiency of vehicle motion.

Considering the movement of the vehicle on the road, in the urban traffic conditions, an increased participation of velocity profile move complex can be seen. Therefore the number of cycles of acceleration and braking have been increased and the duration of the predetermined movement is decreased. This leads to a reduction in the overall efficiency of vehicle's movement relative to the efficiency that can be achieved in the extra-urban driving conditions. It turns out that the energy balance for urban cycle, only about 9% of energy from fuel is processed on vehicle movement [1–2]. The rest of the energy is irretrievably lost. The largest energy loss is generated in the piston combustion engine.

For many years, new and better methods of processing and supplying power to the wheels of the vehicle has been searched for increasing the overall efficiency during movement. Beside the internal combustion engine, there were lots of energy converters, motors, which were supposed to be implemented. The first source of the wheeled vehicle drive in the history was a piston steam engine developed by James Watt, which supplied the energy needed to process the movement at the end of XVII century. Another attempt was taken again and at the turn of the twentieth and twenty-first century, by developing the steam engine (ZEE) [4–5]. The engine with only 24% of maximum efficiency emits harmful exhaust components in an amount close to zero. Driving torque reaches more than 350 Nm at the lowest rotational speed. The maximum effective power describes that unit reaches 50 kW. Unfortunately, due to the low efficiency and continuous rapid development of units with internal combustion the construction has not been accepted.

At the turn of years there were attempts of using other available types of engines. Starting from an electric motor, a Stirling engine, ending with the gas turbine. Currently, only two solutions are accepted. Piston combustion engine because of known and common construction and its modifications [3]. And electric motor at the second place, which is characterized by high efficiency, ease of control and simply construction. It should be noted that the first electrically driven vehicle Lohner-Porsche was created at the beginning of the twentieth century. Further development of electric vehicles took place at the turn of the last twenty years.

The electric motor, which is a good and efficient energy converter, however requires external power supply to move the wheels of the vehicle. The biggest problem now is the carrier of electric energy. Supplying it with a power system using contact methods becomes too expensive and complicated. Currently produced electrochemical batteries for storing energy are heavy. The dimensions of the battery are big, and the amount of accumulated electric power is small [6]. The unit of energy density of battery is much smaller than for conventional petroleum fuels. This contributes to the significant reduction of the possible distance to be traversed than a classical vehicle equipped with the combustion engine SI or CI. Large batteries also require additional cooling because there is a possibility of overheating which may cause damage. At the moment of a road collision there is the possibility of damaging the battery enclosure, which may lead to dangerous for human and environmental leakage of electrolyte.

Therefore, the Department of Vehicles and of Fundamentals of Machine Building made the attempts to develop a method of supplying the electric power to the vehicle, to reduce the capacity of the battery to the maximum, and to allow unlimited movement on the road by creating the infrastructure for supplying the vehicles with power. Discussed method involves the use of the electric drive in tested vehicle with contactless energy transfer. The current knowledge and technology point the possibility of such a method with a very high efficiency transmission, which can reach more than 90% [7 – 9]. Besides it is known that the similar works have been taken earlier by the representatives of the automotive industry [10].

2. Test vehicle

In the research was used Smart Fortwo, model of the first generation, produced by Mercedes-Benz from 1998 until 2007. The car was owned by the Department of Vehicles and Fundamentals of Machine Building. The car was equipped with three-in-line engine (SI) with a capacity of 599 cm³. Maximum power of this engine was 45 hp (33 kW). Maximum torque was 70 Nm. Figure below (Fig. 1) shows described car.



Figure 1 Test vehicle

The drive system of the vehicle was modified and adapted to the electric drive. SI engine was removed and replaced with electric motor DRE132S4/FR/TH/ES7S which develops the maximum power of 4 kW. Control and engine power is operating by electronic power converter MOVIEDRIVE. In addition, thanks to the wiring system, there was a possibility to control the converter. The main control signal, forcing the movement of the vehicle, is the position of the accelerator pedal which is achieved by potentiometer installation. Picture two (Fig. 2) shows the vehicle with assembled electric motor.

Operation system is based on inductive transmission of electric power. Electromagnetic coupling is formed with the participation of the air gap by combining the two coils which are respectively a transmitter and a receiver. Then, the energy will go to the battery charging circuit first, and after that at the next stage, will be transferred to the converter. This will reduce the overall efficiency of the system, but nevertheless it is believed that it will be higher than in the classical drive system.

Łaziński, P.

The purpose of a trial, in the initial phase of work, is supplying electricity to the vehicle using a cable from the power grid. After checking the operation of the driving system in the test vehicle the energy will be supplied wirelessly to the engine by MOVITRANS system.



Figure 2 Test vehicle with assembled electric motor (rear view)



Figure 3 The physical model of the vehicle

516

3. The numerical model of vehicle

The vehicle motion in the process of numerical modeling is described by physical fifth-mass model of the vehicle which in the rectangular Cartesian space has seven degrees of freedom. The physical model of the vehicle is shown in the figure three (Fig. 3). This figure shows the impact of conservative and non-conservative external forces that occur during movement of the vehicle. To allow a mathematical model description by commonly known the principles of mechanics, the physical model was simplify. Each of the model mass is treated as a rigid mass. Unsprung masses of vehicle wheels are connected rigidly with a main mass. The suspension has been omitted because the vehicle movement on a flat road is taken under consideration. The surface is characterized by constant longitudinal and lateral adhesion coefficient which are equal for each wheel. There is no drift in the mark of cooperation wheels with the surface during the movement. The planes of the wheels are parallel to the symmetry plane of the vehicle.

The mathematical model of the vehicle motion was led out from the Lagrange equations of the second kind for the assumptions of the physical mode.

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_j}\right) - \frac{\partial T}{\partial q_j} + \frac{\partial D}{\partial \dot{q}_j} + \frac{\partial V}{\partial q_j} = Q_j \quad j = (1, ...7)$$
(1)

The impact of the field of gravitational potential, and so the potential energy of the system has been omitted in further consideration. It was assumed that the vehicle motion is carried out without changing the height of the movement. For the presented case the vehicle movement was formulated by the following equations:

$$\begin{split} m\ddot{x} + F_{pow} &= F_{x.1} + F_{x.2} + F_{x.3} + F_{x.4}m\ddot{x} + F_{pow} \\ &= F_{x.1} + F_{x.2} + F_{x.3} + F_{x.4} \end{split}$$
(2)

$$J_{zc}\ddot{\varepsilon} = (-F_{x_1} + F_{x_2} - F_{x_3} + F_{x_4})\frac{1}{2}b + (F_{y_1} + F_{y_2})a_c$$

$$- (F_{y_3} + F_{y_4})b_cJ_{zc}\ddot{\varepsilon} = (-F_{x_1} + F_{x_2} - F_{x_3} + F_{x_4})\frac{1}{2}b \qquad (3)$$

$$+ (F_{y_1} + F_{y_2})a_c - (F_{y_3} + F_{y_4})b_cm\ddot{y} = F_{y_1} + F_{y_2} + F_{y_3} + F_{y_4}m\ddot{y}$$

$$= F_{y_1} + F_{y_2} + F_{y_3} + F_{y_4}$$

$$(J_{koa_1} + J_{red_s}) \ddot{\varphi}_{k1} + F_{z_1}e = M_{n1} - M_{h1} - F_{x_1} (J_{koa_1} + J_{red_s}) \ddot{\varphi}_{k1} + F_{z_1}e = M_{n1} - M_{h1} - F_{x_1}$$
(4)

$$(J_{koa_{-}2} + J_{red_{-}s})\ddot{\varphi}_{k2} + F_{z_{-}2}e = M_{n2} - M_{h2} -F_{x_{-}2}(J_{koa_{-}2} + J_{red_{-}s})\ddot{\varphi}_{k2} + F_{z_{-}2}e = M_{n2} - M_{h2} - F_{x_{-}2}$$
(5)

$$J_{koa_3}\ddot{\varphi}_{k3} + F_{z_3}e = -M_{h3} - F_{x_3}J_{koa_3}\ddot{\varphi}_{k3} + F_{z_3}e = -M_{h3} - F_{x_3}$$
(6)

$$J_{koa_{-4}}\ddot{\varphi}_{k4} + F_{z_{-4}}e = -M_{h4} - F_{x_{-4}} \tag{7}$$

Numerical solution of equations of motion were made by the method of Euler, which is a special case of Runge-Kutta methods. The simulation program was created in the Pascal programming language. An error of method which has been used to the integration step and arithmetic floating point of computer, imposed the need for analysis of the convergence result. The results of this analysis is shown on the graph (Fig. 4). On that base an optimal integration step has been selected.



Figure 4 Convergence graph of the results of numerical calculations

4. Testing the process of movement

4.1. Numerical research

For validation of testing vehicle there were made the series of numerical tests which were designed to confirm that it works. It was decided to test the process of acceleration of the vehicle. Research has allowed to determine an expected value of acceleration and speed achieved by the test vehicle driven by an electric motor. Additionally, numerical testing allowed to determine the maximum gear ratio where the test vehicle gains speed. Assumed that the acceleration process takes place on a flat, horizontal surface with longitudinal factor of adhesion is equal $\mu_x = 0.8$. Wind gusts were omitted. In the simulation, the weight of the vehicle corresponds to the weight of the vehicle with the driver and research equipment. Numerical testing showed that a mounted engine is able to accelerate vehicle efficiently even in the fourth gear ratio. Acceleration of the testing vehicle on the higher gear becomes pointless. This process can lead to unnecessary thermal overload of engine and consequently to damage it. The graph (Fig. 5) shows the course of simulated process of acceleration with maximum efficiency. On the graph can be seen that the real vehicle, after modification of the drive system, will be able to reach speeds of nearly 30 km/h in fourth gear. Lack of coupling helps to reduce the acceleration time because the switching process is omitted. There were also the numerical research made which showed that there was a possibility to achieve the maximum acceleration of the vehicle from a speed equal to zero to maximum speed in a gear.

518

The graph (Fig. 6) shows characteristic of traction, acceleration for four ratios test, which should be reached by the test vehicle.

It also shows that the greatest acceleration of 1.1 m/s^2 the vehicle should achieve in the first gear. On the fourth gear the largest acceleration should be 0.55 m/s^2 .



Figure 5 The graph of simulation process of test vehicle acceleration with maximum efficiency and the ability to gear changes



Figure 6 The theoretical plot of acceleration of the test vehicle

4.2. Experimental research

For the evaluation of traction parameters of test vehicle and checking whether mounted engine is working properly, the tests of acceleration process were made. Research of the acceleration process were performed on a flat, horizontal and homogeneous surface with paving stones with a constant on the entire length of the road,

	Gear 1	Gear 2	Gear 3	Gear 4
Acceleration 1	1.3	1.4	1.1	1.0
	m/s^2	$\rm m/s^2$	$\rm m/s^2$	m/s^2
Acceleration 2	1.3	1.3	0.9	1.0
	m/s^2	$\rm m/s^2$	$\rm m/s^2$	m/s^2
Acceleration 3	1.7	1.3	1.0	0.8
	m/s^2	$\rm m/s^2$	$\rm m/s^2$	m/s^2
Acceleration 4	1.6	1.3	1.0	0.9
	m/s^2	$\rm m/s^2$	$\rm m/s^2$	m/s^2
Acceleration 5	1.7	1.4	0.9	1.1
	m/s^2	$\rm m/s^2$	m/s^2	m/s^2
Reached speed	10.2	15.1	17.4	10.5
	km/h	$\rm km/h$	$\rm km/h$	km/h

Table 1 The results of acceleration measurements

longitudinal coefficient of adhesion. The research was made on a windless day, but the car has been moving in two directions, to eliminate the inclination of the road or a general inclination of area. The test vehicle was loaded by research devices. The weight of the vehicle includes the test driver. A series of experimental studies were performed with Decelerometer CL170's made by ZEPWN company. The device is mounted inside the vehicle, as close as possible of mass center, to ensure the solid connection with the vehicle. Due to the use of the device it was installed facing the rear. Setting the appropriate device parameters allowed for measuring the acceleration of the test vehicle. It was measured the real acceleration in two orthogonal axes which lie in the plane of longitudinal symmetry of the vehicle. This eliminates the error associated with the movement of the vehicle body (diving). The conditions in attempts of experimental tests were this same as in numerical research. Experimental study of the acceleration process for maximum acceleration was carried out at each of the four ratios of the speed from zero to the maximum possible speed, as in the case of numerical studies. The results of measurements are shown in Table 1. For technical reasons, it failed to perform the measurement of the maximum speed for each gear. The limitation was the presence of the power cord, which supplies electric power to the engine in this version of the test vehicle. The maximum achieved acceleration was 1.7 m s^2 in first gear. The lowest on the fourth gear was 0.8 m/s^2 . These values are low, but the inseparably connected with the parameters of the installed engine with the maximum torque of only 30 Nm.

5. Analysis of the results

The collected results compared with obtained, thanks to the numerical model, graph of the acceleration for each of the four gears. There is a very clear impact of the run of outer characteristic of engine on the run of acceleration in numerical test on acceleration graph (Fig. 6). There is a big collapse for the ratios of the first and second gear on the graph. The reason is the way of power suppling and controlling of electric motor at the stage of tests on the vehicle. Analyzing the results of numerical and real tests it is noticeable that the maximum speed achieved in the first and second gear overlap. The difference is only a few percent. It shows how properly the parameters of the numerical model were selected. The real acceleration values are higher relative to those obtained by numerical modeling. It may be caused by fact that the engine system with the electronic power converter allows to be overloaded what let to obtain higher rated operating parameters. The numerical model in present form does not include the characteristic of the drive system. The problem may be also the implementation of electric motor controlling, which does not provide the fluidity in the acceleration of the vehicle. It cause rapid jumps in acceleration values, which are also visible in measurements. It should also be noted the proportion between the results of acceleration. The proportion of acceleration between the first and fourth gear of numerical computations is 2. For the real measurements the value is smaller and amounts to 1.6. It is 21% lower, which may also indicate a need to improve the control of motor run.

6. Conclusions

The tests showed that designed drive system is able to set the test vehicle in motion. The nature of the movement is preserved. Tests will therefore contribute to a further optimization of the prototype of vehicle construction and, as required, to improvement the identification of the actual numerical model. Therefore, the whole work should allow to optimize the key issues related to engine control, drive system, and a loading system. The test results will be used as input data to design the optimal control parameters of the engine and parameters of MOVIETRANS system, in which the vehicle will be equipped. In addition, based on research of different gear ratios, there is a need to enable the driver of the vehicle prototype to change these ratios during the vehicle motion. This treatment should result in more efficient use of the energy required to the movement. The continuation of the tests will be research of the precise registration of all motion parameters such as speed and acceleration of the vehicle, the speed of each wheel, electrical values. Voltage and current power of drive system of the vehicle, and the MOVIETRANS system will be recorded. This treatment will allow for the clear identification of the efficiency of the energy conversion built in the prototype vehicle. It will also provide the data of the possibility of using such a system in other vehicles.

References

- [1] Siłka, W.: Teoria ruchu samochodu, WNT, Warsaw, 2002.
- [2] Siłka, W.: Tractive efficiency of a vehicle at variable speed, Combustion Engines, 144, 1, 56–62, 2011.
- [3] Laziński, P. et al.: Research on a prototype spark ignition variable compression ratio engine fitted with a pneumatic energy accumulator, *Combustion Engines*, 159, 4, 54–65, 2014.
- [4] Mößbauer, S. et al.: Zero Emission Engine A Novel Steam Engine for Automotive Application, COMMODIA 2001, 14, 473–478, 2001.
- [5] Scherfling, S.: Zero Emission Engine An Economic and Environmental Benefit, Beuth University of Applied Sciences Berlin, 2007.
- [6] Stachura, A.: Modelowanie dynamiki napędu hybrydowego, Ph. D. Thesis, Silesian University of Technology, 2011.

Łaziński, P.

- Judek, S. et al.: Wysokoczęstotliwościowy falownik napięcia badania symulacyjne, Zeszyty Naukowe Wydziału Elektrotechniki i Automatyki Politechniki Gdańskiej, 21, 125–130, 2005.
- [8] Judek, S. et al.: Analiza systemu przekazywania energii elektrycznej na drodze indukcyjnej przy dużej szczelinie powietrznej i wysokiej częstotliwości, *Czasopismo Techniczne Elektrotechnika*, 1-E, 71–79, 2007.
- Wtorek, C.: Bezstykowy przesył energii elektrycznej oparty o szeregowo-równoległe układy rezonansowe, AGH University of Science and Tehnology, 2013.
- [10] Volvo Car, https://www.media.volvocars.com/uk/en-gb/media/pressreleases/ 134930/volvo-car-group-completes-successful-study-of-cordless-charging-for-electriccars. 2016.

Nomenclature:

- T kinetic energy of the system [J],
- D function of energy dissipation [J],
- V potential energy of the system [J],
- Q_i generalized external force [N],
- q_i generalized j-th coordinate [-],
- j number of degrees of freedom [-].
- x longitudinal acceleration of the vehicle $[m/s^2]$,
- y lateral acceleration of the vehicle $[m/s^2]$,
- ε angular acceleration around the Z_c axis of the vehicle $[rad/s^2]$,
- φ_i angular acceleration of the i-th vehicle wheel [rad/s²],
- J_{zc} moment of inertia of the vehicle around the Z_c axis [kmm²],
- J_{kolo_i} moment of inertia of the i-th wheel [kgm²],

 J_{red_s} - reduced on the axle of the drive wheel the engine moment of inertia [kgm²].

522