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Aspects Concerning the Implementation of Electric Bikes the Urban Transportation of Cluj-Napoca City

Viorel Trifa, Mircea M. Radulescu, Călin Mărginean, Carmen Ciurtin

Technical University of Cluj-Napoca
e-mail: trifa@edr.utcluj.ro

Abstract

The paper is a first stage of a new research devoted to the application of reluctance motors to drive conventional bikes. Electric bike market is one of the most dynamic today, involving a large number of producers and various types of units, concerning technical data and prices. One of the most promising reluctance motor suitable for direct drive of an electrical bike has been chosen and designed accordingly. It consists of an inverse radial stepping motor, with a fixed stator mounted on front wheel shaft and an external toothed rotor fixed on the front wheel itself.

Preliminary design is described with the study of magnetic field in order to provide the optimal geometry of the motor and adequate windings.

Key words: *electric bike market, motor design, finite element field analysis*

Introduction

Individual urban transportation in Cluj-Napoca has blown up since 1990, due to the expansion of car number [1]. This fact has produced a crisis in urban transportation, for which local authorities cannot face satisfactorily. Electric two-wheel vehicles could be the best means for urban individual transportation, provided other conditions be accomplished, as people mentality related to such a transportation mode will change and, not finally, the budget problems.

Electric bike market is one of the most dynamic today, involving a large number of producers and various types of units, concerning technical data and prices [2-7]. The study in this purpose has been made using information available on the Internet. At first sight, one can remark some construction strategies, as:

- most producers use conventional electric motors of DC types, that are cheaper and suitable for light electric vehicles with power of hundred Watts;
- no special batteries are used, only classical lead-acid type;
- conventional 1-quadrant electric drive, with mechanical braking is adopted, from economical reasons, so that no special electronic part is involved.

Electric motors involved in bike driving reveal the most important problem of designing and manufacturing of an electric bike. Hence, this project is focused on motorizing and driving the electric bike. An overview of the electric-bike driving solutions leads to the following conclusions:

- induction motors are not suitable for driving electric bikes, in spite of their costs, due to their low energy efficiency;

- brushed DC motors, of conventional construction, even most popular, are of limited prospect for enhancing bikes' technical performances;

- other solutions, as three-phase brushless DC and AC (permanent-magnet synchronous) motors and three- or four-phase switched reluctance motors are still in research, but only special motor designs will have successful future.

PWM inverters for motor electronic supply are dependent on the motor type. Usually, in case of brushless DC and AC motors, bipolar current inverters are needed, so full-bridge inverters have to be used. In case of switched reluctance motors, unipolar inverters lead to cheaper half-bridge inverters.

As expected, low-power inverters have to be taken into account, at voltages of 24-36V and power up to 500W, according to motor output power. This fact corresponds to a peak bridge-current of 20A. PWM inverter market is also very large, with a great variety of voltages and currents, number of phases etc. From this point of view, there is no difficulty in choosing suitable inverters for supplying the electric-bike motor drive.

Electric drive of the bike

As electric vehicle, the electric bike is an electromechanical device, which converts electric energy provided by battery into mechanical energy for moving its wheels. Away from battery, rider and mechanical structure of the bike, this device consists of an electric drive system. A suggestive scheme of an electric bike is given in Figure 1, emphasizing its main parts: electric motor, power unit (inverter) and controller.

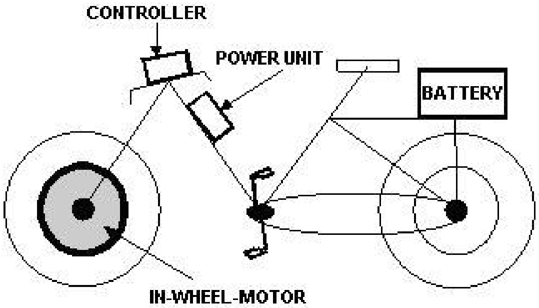

Fig. 1. Scheme of an electric bike.

The main problem encountered with this vehicle refers to the power of electric motor. It may be estimated as:

$$P = 1200*(x+0.05)*y \qquad [\mathrm{W}], \tag{1}$$

where x is the road gradient, and y is the running speed in m/s. This expression is written for a total weight of 120 kg (80kg of the rider and 40kg of the bike itself) for an usual friction coefficient of 0.05. For road gradients between 0 (flat road) and 0.12 (12%) and running speed from 0 to 10 m/s (36 km/h), the motor output power is represented in Figure 2.

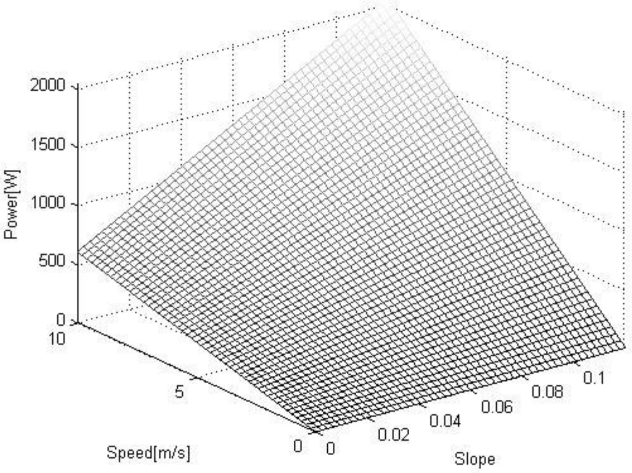

Fig. 2. Graphical representation of power/speed/slope relationship.

Eq. (1) points out that for the ranges given above, needed power is in the range 500-2000W (max power for max speed and max slope). Also, for a given power of 500W, one can reach maximum speeds between 2.5-8 m/s, depending on the road gradient – at a load of 80kg, and 20-30% higher speeds – at a load of 60kg, as shown in Figure 3.

Preliminary calculus indicates satisfactorily results below 500W, in accordance with the existing performances on current market.

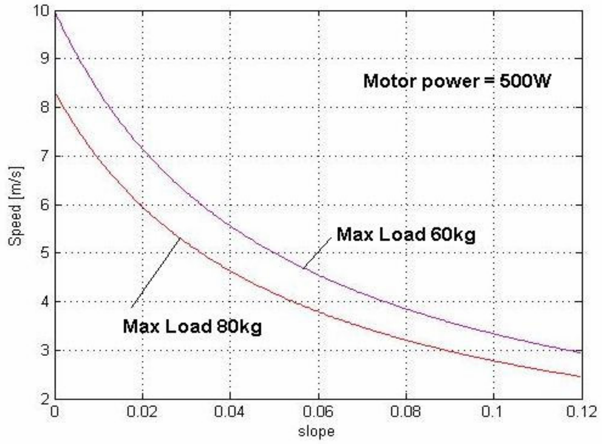

Fig. 3. Variation of maximal speed with road gradient.

Designing the reluctance motor

In-wheel drive of the bike involves the placement of the electric motor inside the front wheel, which is a direct drive. Accordingly, a high-torque, low-speed motor is to be designed for this application. Electric reluctance motor of reverse construction (inner stator – fixed on the wheel shaft, and outer rotor) has been considered for this study. A 16-pole, 4-phase motor (4 poles/ phase) is proposed, as shown in Figure 4.

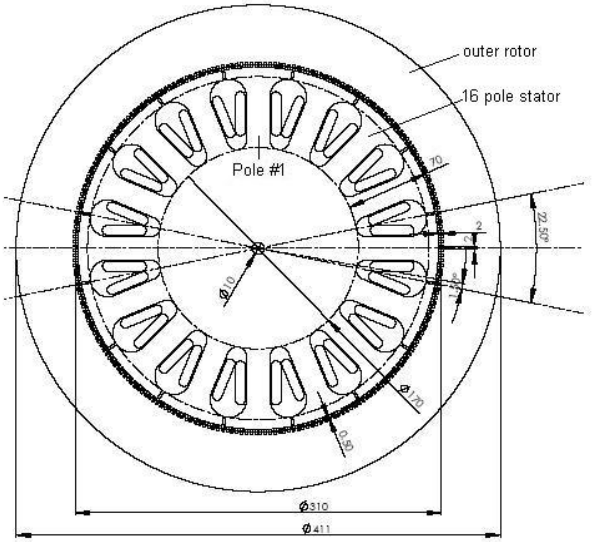

Fig. 4. Cross-section of the reluctance motor.

The 4 phases are respectively placed on poles 1-5-9-13, 2-6-10-14, 3-7-11-15, and 4-8-12-16. Accordingly, the motor phase #1 is schematically represented in Figure 5. Each phase is built by 4 series-connected windings, with alternate magnetic orientation.

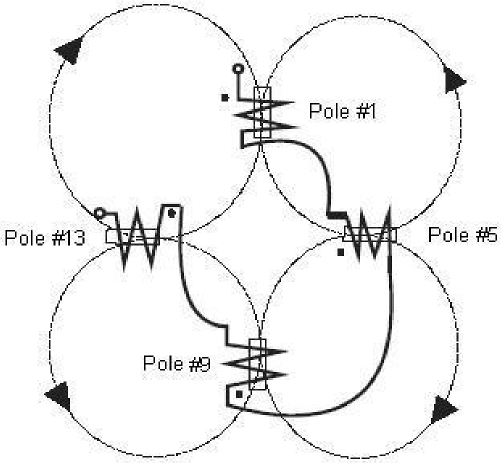

Fig. 5. The winding placement of phase #1.

Toothed structure of the motor

As a reluctance motor, the structure of the air-gap is similar to the variable-reluctance stepping motors. This structure offers the reduction of the rotor movement, to acquire the requirement of a direct drive. Figure 6 shows a detailed picture of the toothed structure.

The rotor has z_r = 244 teeth, identical in size with each of z_s = 14 teeth/stator pole. The key dimension is the amount of the tooth b = 2 mm, as taken for study. With these starting quantities, and using some additional calculations, the following main characteristics of the motor are obtained:
Number of phases m = 4;

Number of steps/revolution N_p = 976 steps/rev;
Number of rotor teeth z_r = 244;
Number of stator teeth per pole z_s = 14;
Tooth dimension b = 2 mm;
Distance between stator poles d = 3 mm;
Air-gap length L = 97.6 cm;
Air-gap diameter Φ = 31.1 cm.
Number of wire turns per pole N = 260.

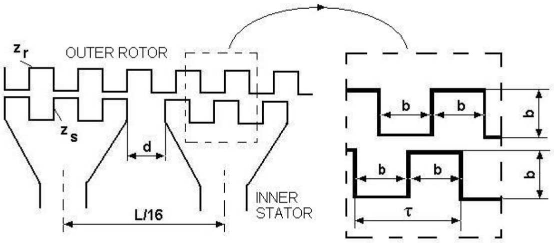

Fig. 6. Stator/rotor toothed arrangement.

These preliminary data lead to general-size motor arrangement, as given in Figure 7.

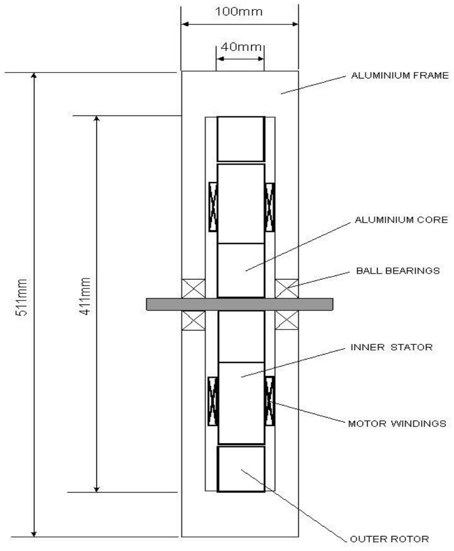

Fig. 7. General-size arrangement of the motor.

As shown earlier, the inner stator is fixed on front-wheel shaft, while the outer rotor is mounted on the wheel rim. The dimensions given in Figure 7 are of first design in our study. The final arrangement of the motor is still in progress.

Speed and torque of the motor

Preliminary study indicates for an usual angular speed of 1 rot/s = 60 rot/min, a motor pulse frequency of 976 pulses/s. With this value, one can calculate the linear speed of the bike as

$$v = \Omega R = \frac{\pi n}{30} R = 1.88\, m/s = 6.78\, km/h, \tag{2}$$

that is an acceptable value for practical purpose.

For this amount, the needed torque, in case of motor power of 500W, results:

$$M = \frac{P \cdot R}{v} = 75\,Nm\,. \tag{3}$$

To obtain such a torque, one must use the simplified torque formula [8]:

$$M_{max} = z_r L_1 I^2\,. \tag{4}$$

For an active inductance L_1 = 0.02H and a phase current I = 5*A,* one obtains M_{max} = *122 Nm.* This value is higher than the needed torque as calculated with Eq. (3), and that is a good option for choosing the power unit.

Field analysis

The motor as it has been designed was studied using finite element environment in order to examine magnetic field in the reluctance motor, and to observe the flux density inside critical regions of the magnetic circuit.

FEMM is a commercial finite-element software for two-dimensional analysis of magneto-static configurations [9]. It allows importing geometric data such as stator/rotor lamination contours, from a file provided by a CAD environment, for instance AUTOCAD with *dxf* files. Then the FEMM processor uses Maxwell equations to solve the magnetic field and a post- processor provides graphical results.

Figure 8 shows the picture of the flux linkage provided by the post-processor in case of tooth per tooth position, i.e. the rotor aligned position.

In Figure 9, one can see the picture of flux linkage and density per one pole, again in case of aligned position.

Figures 10 and 11 show the picture of the flux linkages provided by the post processor in case of unaligned position.

Expected values of flux density are observed in both cases, hence validating the motor design.

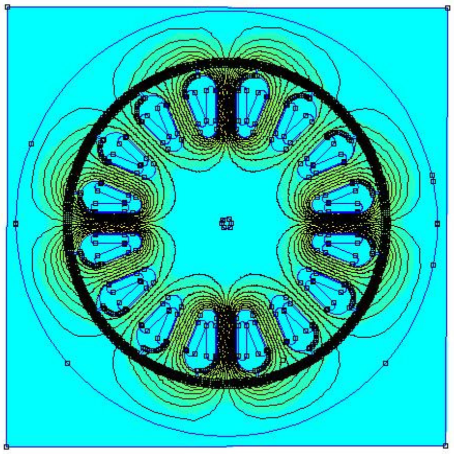

Fig. 8. Flux linkages in case of tooth per tooth (aligned position).

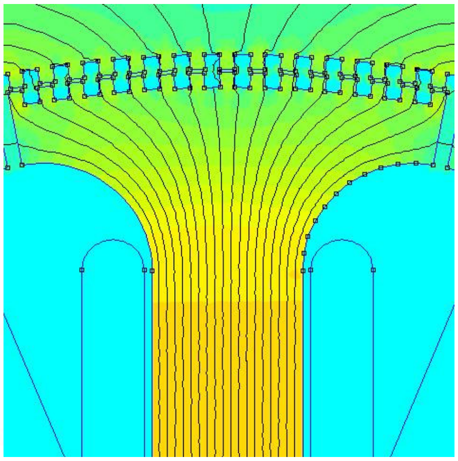

Fig. 9. Flux linkage and density per one pole for aligned position

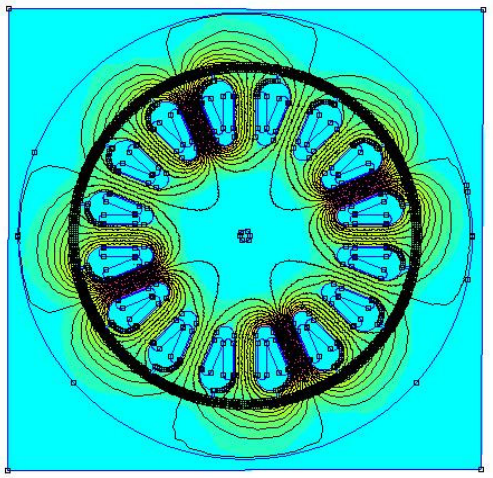

Fig. 10. Flux linkages in case of tooth per tooth pole for position or the rotor (unaligned position).

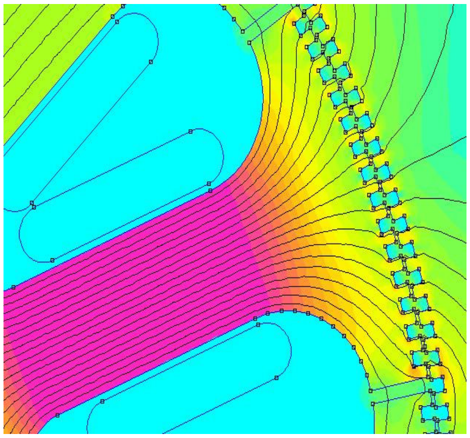

Fig. 11. Flux linkage and density per one unaligned position

Conclusions

A robust electric motor, as reluctance motor, is proposed for direct drive of the front wheel of a bike. Preliminary calculus indicates good performances for this new type of motor and field analysis shows expected flux density values, confirming a good preliminary design of the motor.

The project will continue with a comparative study of various external dimensions of the motor, such as motor diameter and axial length in order to find the most economic and efficient solution for electric bike's driving.

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Aspecte privind implementarea bicicletelor electrice în transportul urban din municipiul Cluj-Napoca

Rezumat

Lucrarea prezintă o nouă direcţie de cercetare dedicată acţionării bicicletelor electrice cu motoare electrice reluctante. Piaţa bicicletelor electrice este astăzi una dintre cele mai dinamice, implicând un număr mare de producători şi diverse tipuri de unităţi, atât în privinţa caracteristicilor tehnice, cât şi a preţului. Unul dintre cele mai promiţătoare tipuri de motoare reluctante, potrivit pentru acţionarea directă a bicicletelor electrice, a fost ales pentru studiu şi proiectat. Presupune un motor pas cu pas radial de construcţie inversată, cu statorul fixat pe arborele roţii-faţă şi cu rotorul dinţat fixat chiar de roata-faţă. Proiectarea preliminară continuă cu studiul câmpului magnetic pentru obţinerea unei geometrii optime a motorului şi alegerea înfăşurării.