# A CASE STUDY REGARDING THE IMPLEMENTATION OF AN ELECTRIC BICYCLE USING RELUCTANT MOTORS

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*Abstract* – **The paper deals with an overview regarding the implementation of individual urban transportation using reluctant motor driven electric bicycles. A particular case of Cluj-Napoca city is taken as reference. Study of opportunity, state of the art in the field of electrical driven bikes and a proposed solution in this field are presented. Preliminary calculus and results are given.**

***Keywords***: *electric bike, in-wheel drive, reluctant motor, preliminary results.*

## 1. INTRODUCTION

Individual urban transportation in a crowded city as 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. Electric drive by brush or brushless DC motors, of conventional construction, is almost exclusive in this case. Beyond market information, recent studies of Chinese and European scientists show certain tendency referring to electric bikes improvements. Following actual trends and taking into account specific traffic conditions in Cluj-Napoca, there is a good opportunity to approach the research of in-wheel direct drive motorizing. In this purpose, a new solution with electric reluctant motor is proposed and described.

## 2. STATE OF RESEARCH IN THE FIELD

### 2.1. Electric bikes

2-wheel electric motor based autonomous vehicles, designated for short and medium distance urban individual displacements are most common [2]. They belong to larger family of 2-wheel vehicles, which includes city bugs (no-seat cycles), electric bikes and electric scooters [3-7].

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. Table 1 shows some representative units of this market, taking into account the main characteristics of electric bikes [2].

*Table 1*

| Model & Producer | EB01-RD WJ Power Sports,USA | ES-501 Yongkang Sport Elect. Vehicle Manf.,China | Currie/EVG folding electric bike, NyceWheels, USA |
|---|---|---|---|
| Max load [kg] | 125 | 150 | Not specified |
| Weight [kg] | 55 | 40 | 27 |
| Max speed [km/h] | 30 | 20 | 20 |
| Range [km] | 50 | 40 | 10 |
| Electric motor | Brushless dc, 250W | NS 250W | Brushless dc, 240W |
| Battery | 3x12V, 12Ah | 36V, 12Ah | 24V, 20Ah |
| Price [USD] | 549 | 240 | 600 |

This study has been made using info documentation from the Internet. At first sight, one can remark some construction strategies, as:

- most producers use conventional electrical motors of DC types, that are cheaper and suitable for electric traction within powers of hundred Watts;
- no special batteries are used, only conventional lead-acid type;
- conventional 1-quadrant electrical drive, with mechanical braking is adopted, from economical reasons, so that no special electronic part is involved;
- most information provided by other producers, shows the ride speed up to 30 km/h, motor output power under 500W, ride range under 50km and prices of

hundred US dollars. The prices are also dependent on looking characteristics.

2.2. **Electric motors involved**

This aspect consists in the most important problem of designing and manufacturing of an electric bike, thus this paper is focused towards motorizing and driving the electric bike. An overview of main solutions for electrical drives as given in Table 2, taking into account some specifications that could make difference between them [2].

*Table 2*

| Electric motor type (within hundred Watts) | Max efficiency [%] and Specific power [kW/kg] | Control strategy | Specific cost [$/kW] |
|---|---|---|---|
| 3-phase Induction motor | 72<br>0.04 | Vector control, DTC | 700 |
| PM Brush DC motor | 75<br>0.028 | PI torque control | 1000 |
| Brushless DC motor | 82<br>0.2 | Self-commutation | 2000 |
| 3-phase PM-synchronous motor | 90<br>0.3 | Vector control, DTC | 3000 |
| 3,4-phase Switched reluctance motor | 85<br>0.15 | Self-commutation | 2500 |

Some conclusions provided by this study will be very useful to approach a new solution for motorizing electric bike, as follows:
- induction motors are not suitable for driving electric bikes, in spite of their costs, due to low energy efficiency;
- brush or brushless DC motors, of conventional construction, even most popular, are of limited prospect for enhancing bikes' technical performances;
- other solutions, as 3-phase PM-synchronous motor and 3- or 4-phase switched reluctance motor are still in research, but only special motor constructions will have successful future.

Beyond market information, recent studies of Chinese and European scientists [3-7] show certain tendency referring to electric bikes improvements. Constant efforts are being made to develop alternative types of motor drive systems with equally or almost as good characteristics, but without commutator and brushes (involving maintenance requirements and gear, thus increasing cost and weight of the bike). In this purpose, new driving methods have been approached, such as:
- adopting special construction of electric motors, using non-conventional configurations and materials;
- placing the motor directly on front wheel (in-wheel solution) and, therefore, a direct drive is proposed, at low speed and high torque;
- accounting for a 2-quadrant drive, to save more energy from battery.

Of course, ideal electric bike will be obtained when significant improvements are also made in battery construction.

As general conclusion for our paper, we consider to approach the research of in-wheel direct-drive motorizing with an electric reluctance motor, of reverse construction, at 24 or 36V, properly designed for low speed, high torque, open or closed loop controlled (self-commutated), at an output power below 500W.

## 3. ELECTRICAL 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 mechanic structure of the bike, this device consists of an electrical drive system. A suggestive scheme of electric bike is given in figure 1, emphasizing its main parts: electric motor, power unit (inverter) and controller.

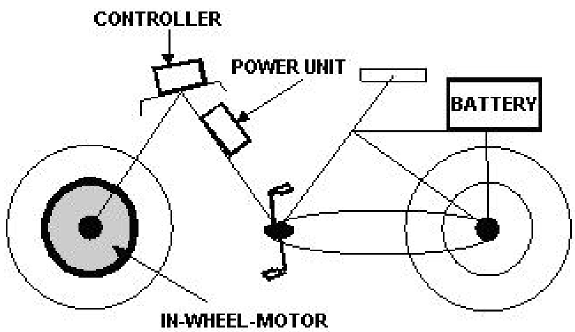


Figure 1. The scheme of electric bike.

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

$$P = 1200 \cdot (x + 0{,}05) \cdot y \ [W] \qquad (1)$$

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 a usual friction coefficient of 0.05. For road gradients between 0 (horizontal 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.

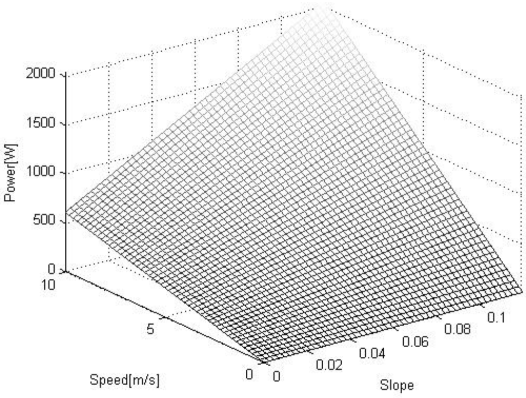


Figure 2. Graphic representation of power/speed/road slope relationship.

Expression (1) shows 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. Preliminary calculus indicates satisfactorily results below 500W, in accordance with the existing performances on present market.

## 4. DESIGNING THE RELUCTANCE MOTOR

In wheel drive of the bike involves the placement of the electric motor inside the front wheel, that is a direct drive. Accordingly, a high torque- low speed motor is to be designed for this application. Electric reluctant motor of reverse construction (inner stator – fixed on the wheel shaft, and outer rotor) have been taken for study. A 16 pole, 4 phase motor (4 poles/phase) is proposed, as shown in figure 3.

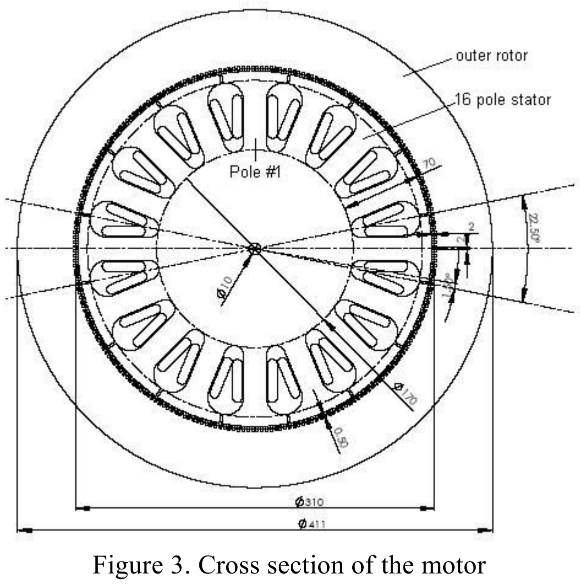


Figure 3. Cross section of the motor

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 schematic represented in figure 4.

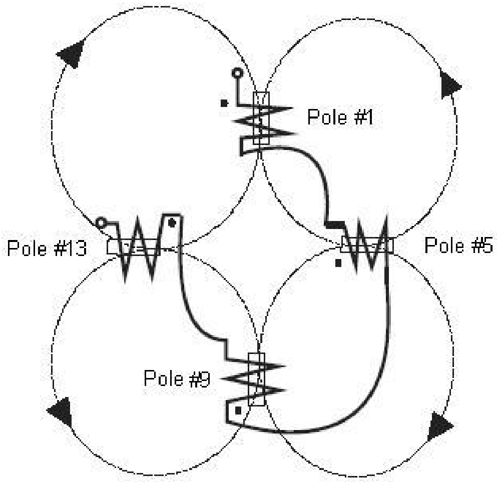


Figure 4. The winding placement of phase #1.

Each phase is built by 4 series mounted windings, with alternating magnetic orientation.

### 4.1. Toothed structure of the motor

As a reluctant 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 5 shows a detailed picture of the toothed structure.

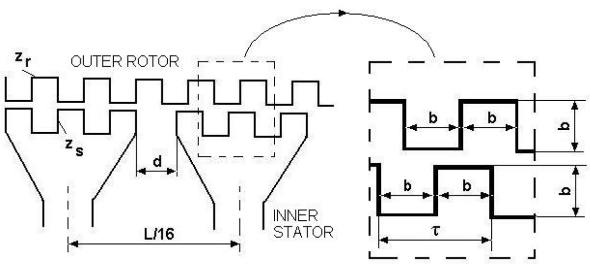


Figure 5. Stator/rotor toothed arrangement.

The rotor has $z_r$ = 244 teeth, identical as dimensions 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 magnitudes and using some additional calculations, the following main characteristics of the motor were 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 $\Phi = 31.1$ cm.
These preliminary data lead to general sized motor arrangement, as given in figure 6.

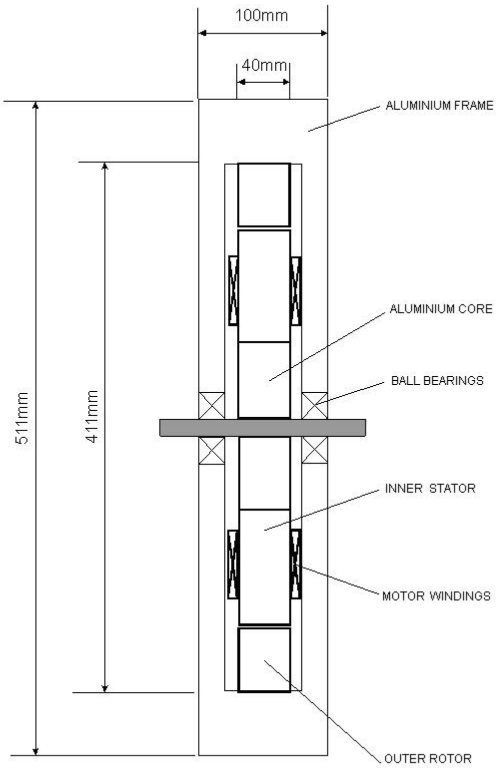


Figure 6. General arrangement of the motor.

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 6 are of first try in our study. The final arrangement of the motor is still in progress.

### 4.2. Speed and torque of the motor

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

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

that is an acceptable value for practical purpose.
For this amount, the needed torque, in case of motor power of 500W:

$$M = \frac{P \cdot R}{v} = 75\, Nm \quad (3)$$

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

$$M_{\max} = z_r L_1 I^2 \quad (4)$$

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

## 5. CONCLUSIONS

A robust electric motor, as reluctant motor, is proposed for direct driving the front wheel of the bicycle. Preliminary calculus indicates good performances with respect to requirements of an individual transportation vehicle in case of a hilled city as Cluj-Napoca. Basic elements are presented, but final results will be available when all design is performed.

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