International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 3
ISSN: 2088-5334

Design and Development of a Drive System Integrated a Continuously Variable Transmission (CVT) for an Electric Motorcycle

Tuan-Anh Bui[a,1], Huy-Bich Nguyen[b,*], Van-Hung Pham[a,2], Manh-Toan Nguyen[a,3]

[a] *School of Mechanical Engineering, Hanoi University of Science and Technology, Ha Noi, Viet Nam*
E-mail: [1]anh.buituan@hust.edu.vn; [2]hung.phamvan@hust.edu.vn; [3]toan.nguyenmanh@hust.edu.vn

[b] *Faculty of Engineering and Technology, Nong Lam University, Ho Chi Minh City, Viet Nam*
E-mail: [*]nhbich@hcmuaf.edu.vn

***Abstract*— Electric motorcycles are widely used in developing countries due to they have some advantages of electric vehicles such as not using Petro-fuel, saving operating costs, and so on. Especially, they might suitable to drive in small streets and alleyways in some developing country cities. In addition, the use of electric power sources could contribute to decrease the pollution caused by exhaust emission from vehicles using gasoline fuel leading to the environmental protection. Therefore, development the electric motorcycles might be a sustainable direction for transportation system and is interested in many developing countries around the world. Unfortunately, most types of electric motorcycles recently do not integrate a Continuously Variable Transmission (CVT) into the drive system. This could lead to the problem that they might not ensure a suitable torque at low speeds, especially when traveling in the special traffic conditions in urban areas. This paper presents a design of a drive system including a CVT transmission integrated into a Cygnus motorcycle frame to develop an electric motorcycle with the goal of safe operation, avoiding the phenomenon of sliding and jerking when the speed changes. The results showed that electric motorcycles can operate stably with a maximum speed of 30 km/h, traveling distance about 57 km for each single charge, without jerkiness phenomenon when accelerating or deceleration as common electric motorcycles in the market.**

***Keywords*— CVT transmission; electric motorcycle; drive system; torque.**

I. INTRODUCTION

Electric motorcycles and electric bicycles are used increasingly widely due to their convenience and certain advantages for gasoline-powered vehicles. Using electricity will contribute to solving the problem of environmental pollution for means of transport. In Vietnam, Electric motorcycles have become a popular transport for students, seniors, and office workers. However, the characteristics of urban traffic, road users need to stop or move every time they encounter traffic signals or go uphill or downhill when participating in overpasses or ramp sections, so they must change the speed when passing through crowded areas such as school gates, markets, etc. On the other hand, most electric motorcycles in Vietnam do not include a stepless drive part, thus, the motor is directly attached to the executive unit, causing for difficult control of traffic transports in the above-mentioned cases. The characteristics of electric vehicles when the starting torque is small and will not have the relative slippage of friction as motorcycles. Therefore, it is necessary to improve the efficiency of use or increase the safety of people and equipment when participating in traffic.

Due to the need to use clean energy for private vehicles, especially in developing countries, scientists have researched and applied electric motors to electric motorbikes or bicycles. Based on scientific and technological achievements, the research results are increasingly applicable, and the efficiency of using electric motors is higher and safer.

Liu et al said that electric motorcycles can help to reduce carbon emissions for the sustainable development of the environment. Basing on the perceptions of environmental policy, pollution reduction, etc. the motorcyclists can accept electric motorbikes as an alternative [1]. Jeyapandiarajan et al showed a simulation of a chassis analysis for an electric motorcycle to find the most suitable material basing on strength, cost and weight of the chassis [2]. In aspect of traffic noise and emissions, Hernandez et al showed the environmental benefits when using electric motorcycles in comparison with gasoline-powered motorcycles [3]. Marinov et al. proposed a methodology to develop electric motorcycles with different capacities and for different driving conditions. The authors confirmed in a study on the electrical sizing of the electric motorcycle drive that when driving on a flat surface in urban conditions at a constant speed, a rated motor power about 35% is used [4].

When converting an internal combustion engine motorcycle into a battery-powered electric one, the life cycle energy consumed and emissions reduced 72% and 45%, respectively. This is significant considerations for the current global issue of transportation [5]. In 2012, David G. Dorrell from Sydney University of Technology and Mircea Popescu from Motor Design Ltd, Elsmere, UK presented the study of electric motor for electric motor. The authors presented a design solution for electric motorcycles based on the use of brushless permanent magnet electric motors (DC or AC) with a wide range of speed and power. The motor can operate at high current density and accelerate in a short time [6]. In 2016, Ruensumruay et al. presented a study of the influence of electric motorcycles on energy consumption in Thailand.

The authors proposed an electric motorcycle model using the Artificial Neuro-Fuzzy Inference Systems (ANFIS). The physical and technical information of motorcycles was collected from survey questionnaires in Bangkok and urban areas. The authors proposed that the important factors that affect the energy consumption of a motorbike are motor size (cc.), longevity (years), distance (km/day), average speed (km/h). Energy consumption in the transport sector is modeled on several scenarios for the number of electric motorcycles in the future. The authors suggested that this development model can forecast energy consumption in preparation for future transport energy planning [7]. In 2012, Tokunaga and Kesamaru presented a development of a new PM motor for sport electric motorcycles.

The authors proposed that the requirement for electric motorbikes is high-performance motors operating at variable speeds. A permanent magnet motor can be operated at rated power with high efficiency but low efficiency at high speeds. Therefore, the authors presented new techniques to improve the efficiency and proposed motor specification for electric motorcycles [8]. An analysis and comparison of control techniques in electric motor drive systems were given by Fernandez and Coello proposed [9].

The authors presented the simulation of two control techniques for an electric motor drive system. The proposed control modes are field oriented control (FOC) and direct torque control (DTC). The analysis involves a comparison between two types of controls and analyzing the advantages and disadvantages of each technique. The purpose is to validate the best technology that is more efficient, easy to implement and most cost effective to carry out in the future on a prototype electric motorcycle. The article contributes to the movement of electric vehicles for students in Cuenca Ecuador, addressing environmental pollution reduction and traffic saturation [10].

Electrical system is one of the most important unit in an electric motorcycle which determines the capacity, travelling distance of the vehicle. A design of electrical system for racing electric motorcycles has been proposed by Blissett et al with purpose of maximizing the vehicle performance in race conditions [11], [12]. Matey et al. presented a design and fabrication of a e-bike with power source from battery and it can be upgraded to use solar energy from solar panels [13]. To improve the travelling distance of an electric motorcycle, Phan et al. proposed two additional charging methods by using solar panel and braking system for a commercially electric motorcycle [14]. Solar energy will become a potential power source for electric motorcycles or other electric vehicles [15], [16], [17], [18]. Ibanez at al presented a study on extending the autonomy of a battery for electric motorcycles by adding a supercapacitor bank to a lithium-ion battery pack. The authors said that the battery capacity is extended up to 7.8% but an extension of the net capacity of the whole system is only 3.7% due to the losses from the converter [19]. Electric motor parts are not always suitable for electric motorcycles, designers need to design some parts to fit the existing chassis but with the right structure and minimize weight as possible [20].

The current mileage for electric bicycles has also been highly enhanced, with models that use Lithium battery technology to cover distances of up to 80 - 90 km on a single charge. Most electric bicycles on the market today have relatively short distances compared to motorcycles. With battery models can only go 20 - 40 km per a single charge. In addition, electric motorbikes are also an alternative to gasoline-powered motorcycles, which are powered by electric motors of less than 4 kW, the maximum design speeds do not exceed 50 km/h. With the ability to travel about 70-100 km on a full charge, the electric motorbikes cost much less money than when using a motorbike as a traffic transportation throughout the year.

However, like electric bicycles, most electric motorcycles attach an electric motor directly to the driven shaft or via a mechanical transmission with a fixed ratio, which also presents the disadvantages as described above. These motorcycles do not yet have CVT stepless drives, the motor is directly attached to the actuator, making it difficult to control, having a small starting torque, and no relative slippage as using a friction clutch of motorcycle. Therefore, the research team is interested in improving the efficiency of using electric motors on electric motorbikes with a solution to improve mechanical properties based on the research of integrating a CVT system into a motorbike drive system.

II. Materials and Method

A. Design of a Drive System Integrated a CVT Transmission

Starting from the requirement of integrating electric motor and CVT transmission into an old motorbike frame, the drive system diagram is described as Fig. 1. The CVT transmission is designed based on the motor housing and drive shaft of the Cygnus motorcycle. Replacing damaged or unreasonable parts, rearranging transmissions reasonably so that CVT transmission can be installed on the existing motorbike frame. The DC electric motor selected is a BLDC motor with a power of 1000 W, the speed of motor shaft of 3000 rpm, using a 48 V power source. Therefore, the electric power supplying for the motor is designed including four batteries of 12V, 20Ah connected in series. The vehicle travel time with maximum motor power is determined as follows:

$$T = \frac{U_{AQ}.I_{AQ}}{P_{DC}} \quad (1)$$

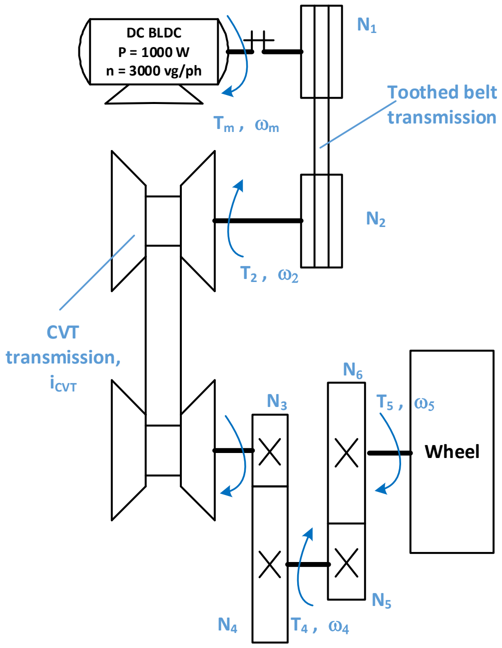


Fig. 1. Dynamic diagram of the drive system using CVT transmission

With the design parameters, the running time is calculated as T = 1.92 hours for each single charge. On the other hand, the ratio of the CVT transmission is designed to vary in a range of 0.5 - 2, while the existed gear transmissions with a total ratio of 1: 7.8 is located in front of the wheel axle (as shown in Fig. 1). So, the maximum wheel speed is determined as follows:

$$V_{\max} = \frac{n \times \pi D}{7.8 \times 60 \times 10^3} \quad (2)$$

The output shaft of the motor is fitted with a toothed drive belt, which is selected to fit with the existing motorcycle body frame, the basic parameters of the drive system are described in Table 1.

TABLE I
BASIC PARAMETERS OF THE DRIVE SYSTEM

Specification	Value
Number of teeth of toothed pulley, $N_1 = N_2$	60
Teeth pitch of pulley and belt, $p_1 = p_2$ (mm)	5.08
Pulley diameter, $d_1 = d_2$ (mm)	97
CVT transmission ratio	0.5 - 2
Ratio of gear transmissions (N_3/N_4).(N_5/N_6)	1/7.8

With the parameters selected to match the existing motorcycle body structure, the CVT transmitter needs to design to be able to create a continuous range of ratios within the designed range. Thus, the force system will take care of moving the mobile pulley part in the CVT transmission. The power analysis diagram on pulley is illustrated in Fig. 2.

When the CVT transmission reaches the largest ratio, the active and passive pulley parts diameters are 28 mm and 84 mm, respectively, the belt velocity is then 13.2 m/s, which corresponds to the maximum motor speed of 3000 rpm. The force exerted on the sliding pulley part is calculated by 61.18 N. The force exerting on the sliding pulley part is determined by the formula as follows:

$$F_n = F.\tan\alpha \quad (3)$$

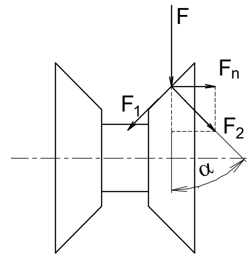


Fig. 2. Schematic analysis of force applied on sliding pulley

Therefore, the force F_n which is necessary to ensure the displacement of the pulley, is calculated by 209,6 N. This force is generated from the kick-offs system when the vehicle is in operation, pushing the pulley in contact with the transmission belt. The drive system integrated a CVT transmission is depicted in Fig. 3, including (1) CVT housing, (2) moving part, (3) left cone pulley, (4) (13) M10 nut , (5) bearing, (6) blocking plate, (7) right cone pulley, (8) axle bearing, (9) ball bearing, (10) CVT transmission case cover, (11) (22) toothed pulley, (12) gasket, (14) (20) key, (15) crankshaft, (16) M10 bolt, (17) toothed belt, (18) (19) M6 bolt and nut, (21) screw. Besides, Fig. 4 (a) shows a 3D view of a base unit for BLDC motor on the Cygnus chassis basing on main parameters and dimensions of the motor housing (Fig. 4 (b)).

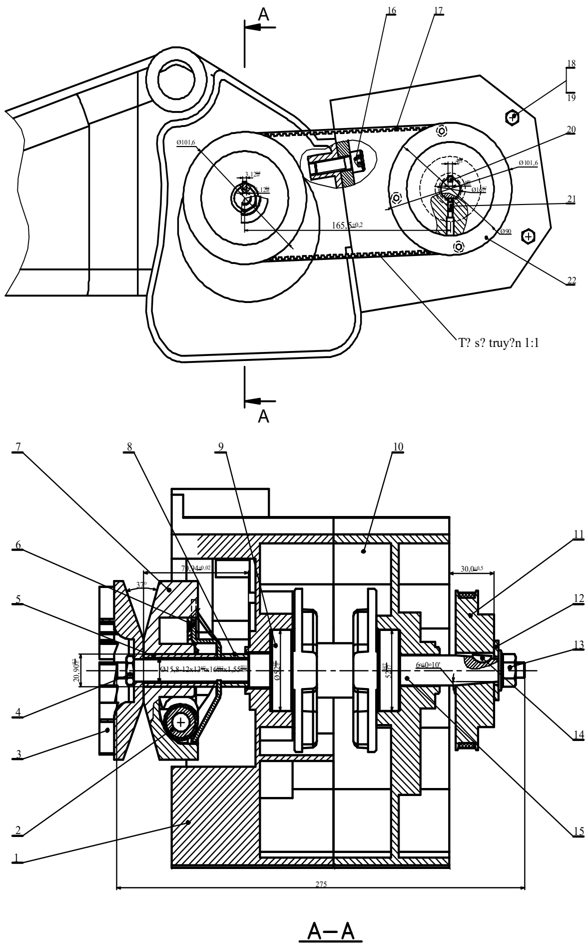
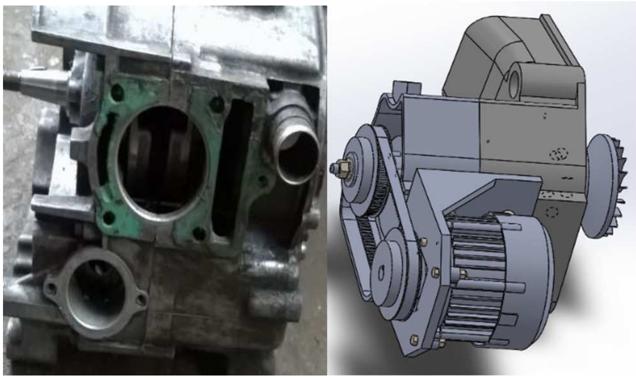


Fig. 3. Drawing of drive system integrated CVT transmission



(a) (b)

Fig. 4. (a) Cygnus motor housing; (b) 3D view of a base design for BLDC motor on Cygnus chassis

The control system is designed with the task of controlling the operation of the vehicle. In which the main components use a power supplied by a system of 4 accumulators connected in series, such as lights, brake lights, turn signals, horns, etc., which are described on the control diagram as shown in

Fig. 5. An integrated control circuit to reverse motor in case of vehicle reverse. The starter switch of the Cygnus motor scooter is designed to be a motor reversing control switch. The vehicle control system with the main unit is a universal control IC (as shown in Fig. 7) that is popular on the market with features designed by the manufacturer to control the opening/closing of the motor, turn signals, brakes, acceleration or deceleration, etc.:

The power supplying the electric motorbike is a 48V-20A accumulator (shown in Fig. 6) which is designed and connected to a charger to ensure the electrical system safe during charging. The control circuit is connected to power source and main motor to control the controlled parts.

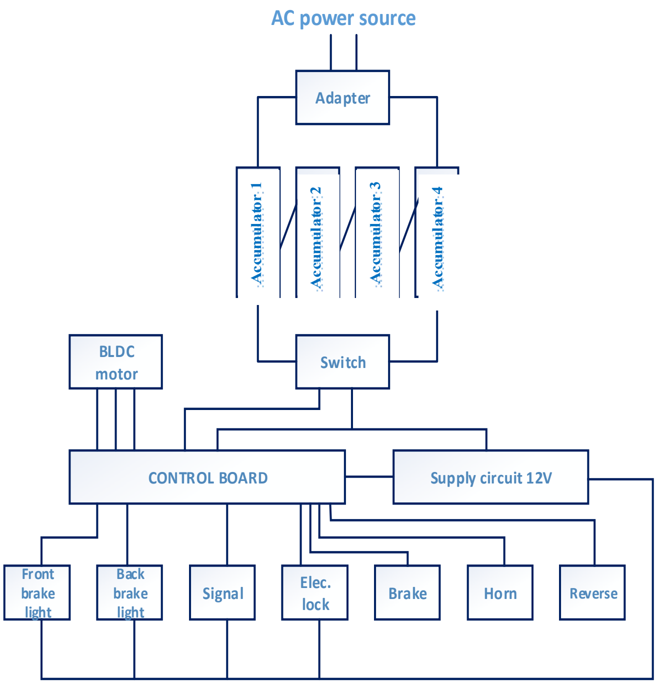


Fig. 5. Diagram of system control design

Fig. 6. Accumulators used as power source for the motorcycle

Motorcycle brakes are designed with an integrated electric lock. When the handbrake braked, the signal would be transferred to the controller to cut off the power to the motor. At the same time, the squeezing will create a traction force on the braking mechanism of the vehicle to slow down and brake the wheel. This is a safety of electric motorbike in comparison with the popular motorcycles when participating in traffic. The control circuit is integrated so that the motor can be reversed. The motor reversing control switch is designed near the position of the motorbike handlebar to facilitate the reverse control when necessary.

Fig. 7. A universal control IC for motorcycle control system

The control system was designed, manufactured and tested the working status of the system in case of traffic. The tests were carried out to assess the stability of the system before being integrated into electric motorcycles. It shows that the designed and manufactured parts are suitable for integrating the CVT transmission into the Cygnus motorcycle body frame, promising a stable system with design parameters.

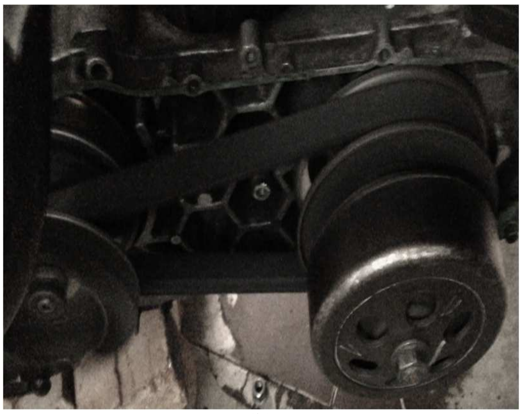
B. Development of an Electric Motorbike with a CVT transmission

The drive system integrates a CVT transmission system which has been designed, manufactured and installed in the body frame of the motorcycle, replacing the drive system using the petrol engine of the vehicle. A BLDC motor is installed with a few parts that have been designed and fabricated to fit the Cygnus body frame as shown in Fig. 8.

Fig. 8. Cygnus body frame with an electric motor

The main components of the motorcycle's drive system, including a belt-pulley transmission, a CVT transmission, etc., have been designed, fabricated, and assembled into the body frame as described in Fig. 9 (a) The electric system was installed with fire safety requirements. The control system was installed and connected with carefully controlled parts of the motorcycle. After installing the new driving, electrical and control systems, the electric motorbike was formed and it was necessary to test its performance. After installation, the tests were conducted to find out the most appropriate set of control parameters for electric motorbikes in urban Vietnam. All tests of the distance traveled have been carried out under the same conditions as the same driver weighing about 60 kg, traveling in daylight and on the same test road.

(a)



(b)

Fig. 9. Drive system integrated with CVT transmission: (a) power transmission by a pulley-belt drive, (b) CVT transmission

III. Results and Discussion

The results show that electric motorbikes operate stably with the speeds changing from 0 to approximately 30 km/h. The maximum operating time for each single charge is about 1.9 h in accordance with a travelling distance of 57 km. This result is obtained with tests on flat sections and does not have to stop much at intersections. This achievement may be due the speed of electric motorcycle is kept stable, reducing losses due to uphill or frequently turning on/off the motor of motorcycle at intersections where motorbikes must stop. These moving conditions are suitable for electric motorcycles to achieve the highest performance, longer driving time, longer travel distances. These parameters are relatively in accordance with the design requirements. These parameters are like those of electric motorcycles on the commercial market. Studies to improve the running time for each charge or integrate a solar panel into the charging system will be conducted in the future.

The tests to assess jerkiness when speeding and decelerating vehicles with actual traffic conditions, especially in intersections and crowded places, have also been performed in Hanoi, Vietnam. The phenomenon of sliding, jerking when accelerating from the state of stopping is no longer happening. Indeed, the acceleration or deceleration is very gradual and gradually creates a sense of safe driving. However, the travelling distance on each single charge is usually shorter than the tests on long, flat roads and fewer intersections. The distance achieved in these tests is approximately 51 km. This may be the losses due to the speed changes on uneven road sections, sections passing through crowded places, uphill or downhill roads, or roads with multiple intersections causing vehicles must stop temporarily. As such, it has satisfied the purpose of integrating a CVT transmission to the drive system to improve the safety of using electric motorcycles in specific urban traffic.

In addition, one of the most important mechanical properties of a vehicle is its wheel torque. The relationship between the torque and speed of the motorcycle will be used to evaluate a design criterion for the ability to operate in urban traffic conditions when the speed needs to be regularly changed. In this study, this relationship will be analyzed to assess the appropriateness of the design and integration of a drive system containing a CVT transmission into the Cygnus body frame. Basing on the dynamic diagram of the electric motor drive system shown in Fig. 1, the torque of the motor output shaft can be described as follows [21]:

$$T_m = -\frac{K_b.K_t}{R_a}\omega_m + \frac{K_t}{R_a}e_a \tag{4}$$

Where, e_a - armature voltage of the motor; K_b, K_t, and R_a are the electric motor constants. Assuming ignoring losses between the transmissions, an expression can determine the wheel shaft torque as follows:

$$T_4 = \frac{N_2}{N_1}.\frac{N_4}{N_3}.\frac{N_6}{N_5}\frac{1}{i_{CVT}}.T_m \tag{5}$$

Where, i_{CVT} - CVT transmission ratio. With motor parameters and transmissions designed, Eq. (5) can be rewritten as follows:

$$T_4 = -\frac{7.8}{i_{CVT}}\left(\frac{1}{10\pi^2}\omega_m - \frac{10}{\pi}\right) \tag{6}$$

The DC electric motor used for the drive system has a maximum torque about 3.2 Nm and the maximum rotation speed of 3000 rpm. With the above parameters, the graph of relationship between wheel shaft torque with motor rotation speed and different CVT ratios can be shown in Fig. 10. It can see that the wheel torque increases when the motor speed decreases with each transmission ratio i_{CVT}. Due to the characteristics of the CVT transmission, when increasing the rotation speed of the motor through the control unit, the CVT transmission ratio also increases accordingly. From the results in Fig. 10 (b), the wheel shaft torque is less affected by the rotation speed of the motor at each ratio i_{CVT}. Thus, in urban traffic conditions that need to be decelerated, the CVT ratio is automatically adjusted accordingly, helping to increase the wheel shaft torque and ensure safe driving conditions.

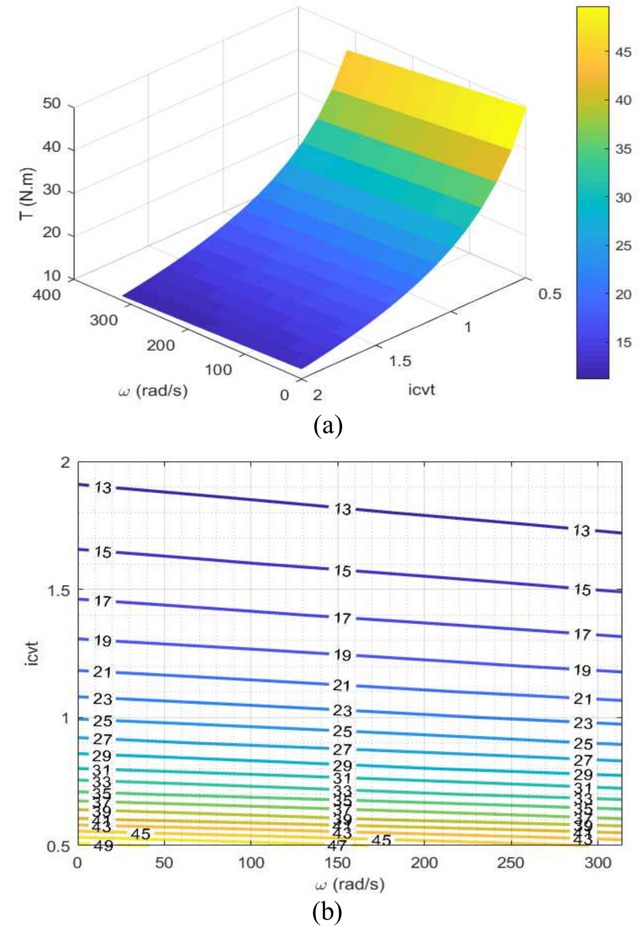


Fig. 10. Relationship of wheel shaft torque vs speed rotation of motor at different CVT ratios

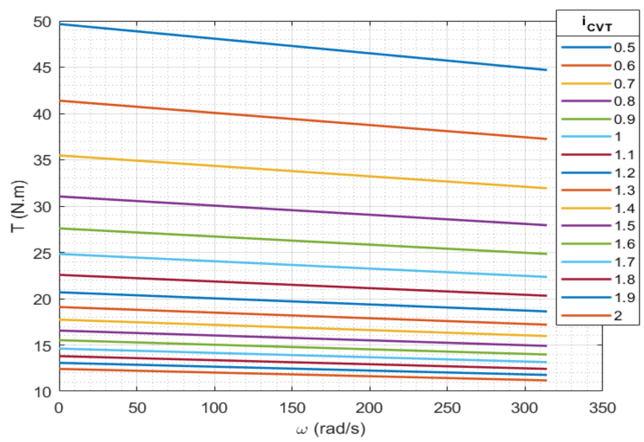


Fig. 11. Wheel shaft torque with different ratios i_{CVT}

The wheel shaft torque can increase to 49 Nm at the minimum speed, then CVT ratio automatically adjusts to 0.5, which makes it easy for the vehicle to move from stationary state to moving state at low speed with high torque. It will help the car to maintain a balanced state, avoiding sudden acceleration. Fig. 11 shows the relationship between wheel shaft torque and motor shaft rotation speed at different i_{CVT} ratios, it can see that the smallest torque of about 13 Nm at the ratio of 2 while the wheel is stationary state and gradually increasing with the infinitely variable CVT transmission. The results show that the torque is almost constant when starting to move from stationary state to a state of rapid motion, this will avoid jerky phenomenon, or accelerate too fast when the vehicle is moving. The simulation results also confirm the advantages of using CVT transmission on electric motorcycles and are the basis for the research team to design and manufacture. When integrated, the efficiency of motor use in the speed range will be improved, increasing the starting torque, contributing to improving the efficiency of electric power use and especially safety for the operator.

IV. Conclusions

A drive system including a CVT transmission has been designed and integrated into the Cygnus motorcycle frame to change the motor into an electric motorcycle with the advantages of a CVT transmission. The results show that the motorcycle operates stably with design parameters with the capable of operating at the maximum speed of 30 km/h and travelling distance about 57 km for each single charge with tests on flat sections and does not have to stop much at intersections. This is because the speed of electric motorcycle is kept stable, reducing losses due to uphill or frequently turning on/off the motor of motorcycle at intersections. The test results also show that the vehicle operates safely in specific urban traffic conditions like in Vietnam without jerk phenomenon when changing speed at the intersections or passing through the crowded places. he analysis of mechanical properties of the drive system shows that the wheel shaft torque is less affected by the rotation speed of the motor at each ratio i_{CVT}. Thus, in urban traffic conditions that need to be decelerated, the CVT ratio is automatically adjusted accordingly, helping to increase the wheel shaft torque and ensure safe driving conditions.

Acknowledgment

This research is funded by the Hanoi University of Science and Technology (HUST) under project number T2018-TĐ-003. Thanks to the Department of Machine tools and Tribology, School of Mechanical Engineering, Hanoi University of Science and Technology helped and supported so much to do this research.

References

[1] Y. Liu, and I. Lai, "The Effects of Environmental Policy and the Perception of Electric Motorcycles on the Acceptance of Electric Motorcycles: An Empirical Study in Macau," SAGE Open, vol. 10, no. 1, pp. 1-14, 2020.

[2] P. Jeyapandiarajan, G. Kalaiarassan, J. Joel, R. Shirbhate, F. Felix Telare, and A. Bhagat, "Design and Analysis of Chassis for an Electric Motorcycle," Mater. Today: Proc., vol. 5, no. 5, Part 2, pp. 13563-13573, 2018.

[3] M. Hernandez, K. Kockelman, J. Lentz, and J. Lee, “Emissions and noise mitigation through use of electric motorcycles,” Transp. Safe. Env., vol. 1, pp. 164-175, 2019.

[4] M. Marinov, V. Valchev, R. Stoyanov, and P. Andreev, "An Approach to the Electrical Sizing of The Electric Motorcycle Drive," in 20th International Symposium on Electrical Apparatus and Technologies (SIELA), 2018, p. 1-4.

[5] P. Y. Xuan, M. Henz, and J. D. Weigl, "Environmental impact of converted electrical motorcycle," in World Electric Vehicle Symposium and Exhibition (EVS27), 2013, p. 1-8.

[6] D. G. Dorrell, and M. Popescu, "Drive motor designs for electric motorcycles," in IEEE Energy Conversion Congress and Exposition (ECCE), 2012, p. 4354-4361.

[7] S. Ruensumruay, W. Pattaraprakorn, V. Chutiprapat, and P. Bhasaputra, "The study on the effect of electric motorcycle to energy consumption in Thailand," in 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications, and Information Technology (ECTI-CON), 2016, p. 1-4.

[8] D. Tokunaga, and K. Kesamaru, "Development of novel PM motors for sport type electric motorcycles," in 15th International Conference on Electrical Machines and Systems (ICEMS), 2012, p. 1-4.

[9] E. Fernandez, and M. Coello, "Comparative analysis of control techniques in drive systems for electric motorcycle," in 6th International Youth Conference on Energy (IYCE), 2017, p. 1-5.

[10] P. E. Fernández, and M. Coello, "Implementation of electric motorcycle case of study: Cuenca-ecuador," in Congreso Internacional de Innovacion y Tendencias en Ingenieria (CONIITI), 2017, p. 1-5.

[11] J. Blissett, M. Degano, M. Gimeno-Fabra, and P. Wheeler, "Design of electrical system for racing electric motorcycles," in International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC), 2016, p. 1-5.

[12] P. Wheeler, J. Blissett, and M. G. Fabra, "Electric superbike racing — The design and construction of a championship winning electric superbike," in 7th International Conference on Power Electronics Systems and Applications - Smart Mobility, Power Transfer & Security (PESA), 2017, p. 1-5.

[13] S. Matey, D. R. Prajapati, K. Shinde, A. Mhaske, and A. Prabhu, “Design and fabrication of electric bike,” Int. J. Mech. Eng. Technol., vol. 8, pp. 245-253, 2017.

[14] T. Phan, T. Phan, and M. Tang, “Solution of additional charging to electric motorcycles,” Sci. J. Tra Vinh Uni., vol. 1, pp. 115-119, 2019.

[15] A. Siriwattanapong, and C. Chantharasenawong, “Electric motorcycle charging station powered by solar energy,” IOP Conf. Ser.: Mater. Sci. Eng., vol. 297, pp. 012060, 2018.

[16] M. Cengiz, and M. Mamis, “Use of Solar Energy in Electric Vehicles,” Int. J. Eng. Technol., vol. 1, pp. 123, 2015.

[17] M. Saadatmandi, and S. Hakimi, "Optimal Utilization of Solar Energy for Electric Vehicles Charging in a Typical Microgrid," Electric Vehicles in Energy Systems, pp. 129-164: Springer, Cham, 2020.

[18] M. Waseem, A. Sherwani, and M. Suhaib, “Integration of solar energy in electrical, hybrid, autonomous vehicles: a technological review,” SN Appl. Sci., vol. 1, pp. 1459, 2019.

[19] F. Ibanez, A. Florez, S. Gutiérrez, and J. Echeverria, “Extending the Autonomy of a Battery for Electric Motorcycles,” IEEE Trans. Veh. Technol., vol. PP, pp. 1-1, 2019.

[20] L. Cheng, X. Yi, B. H. Min, and K. Haran, "Ring Motor Front Wheel for Electric Motorcycle," in IEEE Power and Energy Conference at Illinois (PECI), 2019, p. 1-8.

[21] N. S. Nise, Control systems engineering, 6th ed., New York: John Wiley & Sons, 2011.