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Dynamometer Test for the CVT System using Spring

Young-Woong Kwon*, Seung-Bok Yang**

** Professor, Department of Smart Automobile Engineering, Seoil University, Korea*
*** Associate Professor, Department of Automobile Engineering, Korea Polytechnics, Korea*
ywkon@seoil.ac.kr

Abstract

As a means to cope with the climate change crisis caused by global warming, automobile manufacturers continue to make efforts to use the driving energy of vehicles as electricity. As a result, parts industry such as battery, motor, and controller are attracting attention. China is often seen in large cities, with electric vehicles such as electric bicycles, electric motorcycles, and small electric vehicles popularized and commercialized, mainly in large cities. However, small electric vehicles are not popular in Korea, which is why the country's topography is high in hills. In order to drive the hilly domestic roads, power performance including vehicle climbing ability should be improved. In order to improve the power performance and the climbing capacity of small electric vehicles, the capacity of the motor should be increased. However, when the performance of the motor is improved, the weight of the motor becomes heavy and the price competitiveness is likely to decrease. In addition, in order to operate a high-performance motor, the power consumption of the battery is rapidly increased, so various problems must be solved. In order to commercialize a small electric vehicle for one or two people who do not emit harmful exhaust gas to the human body in a hilly domestic terrain, it is effective to have a separate transmission system. In this study, we were conducted dynamometer test to produce a continuously variable transmission(CVT) system prototype using a spring that can be applied to a small electric vehicle and to install a CVT system prototype manufactured in a small electric vehicle. The dynamometer test results showed that the maximum speed performance, acceleration performance, and climbing performance were improved.

Keywords: *Dynamometer, Spring, CVT, Dynamic performance, Small electric vehicle*

1. Introduction

The theme of the world's attention is the climate change crisis. The climate change crisis is caused by global warming. Global warming is preventing direct sunlight from the sun and is generated from cracks in the ozone layer surrounding the earth. One of the many factors that cause the cracks in the ozone layer surrounding the earth is the automobile using fossil fuels. Turning the power source of a vehicle from fossil fuels to electrical energy is one of several ways to cope with the global climate change crisis[1. 2, 3]. For this reason, automobile

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Corresponding Author: ywkwon@seoil.ac.kr
Tel: +82-02-490-7418
Professor, Department of Smart Automobile Engineering, Seoil University, Korea

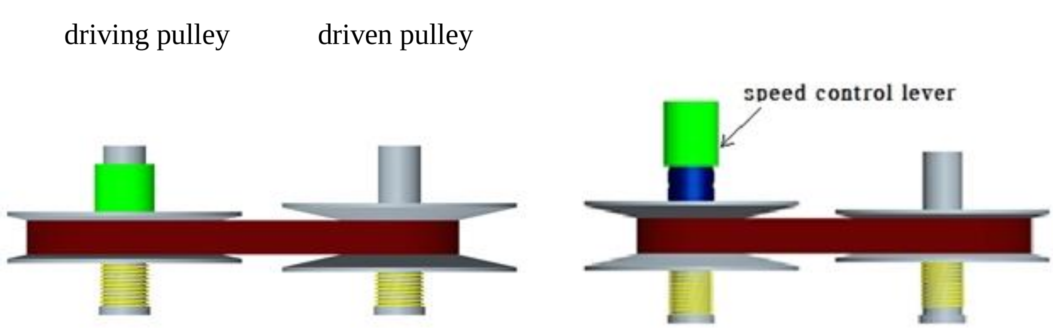
manufacturers around the world are spurring the development of automobiles using electric energy. General vehicles are used to move between cities and cities, but small vehicles are used as a means of moving in cities. In particular, recent studies on the development and commercialization of electric bicycles, electric scooters, and small electric vehicles have been actively conducted along with the "Personal Mobility" listing[4, 5, 6].

Small electric vehicles such as electric motorcycles and electric bicycles, which run throughout the city in large cities in China, can be encountered frequently, but small electric vehicles are not popular in Korea. This is due to the reason for the high hilly domestic terrain, unlike the big cities in China[7, 8]. In order for small electric vehicles to drive hilly roads, power performance including the climbing ability of vehicles should be improved. For this, the capacity of motors used in small electric vehicles should be increased [9, 10, 11]. However, when the performance of the motor is improved, the weight of the motor becomes heavy and the price competitiveness is likely to decrease. In addition, in order to operate a high-performance motor, the power consumption of the battery is rapidly increased, so various problems must be solved. It is effective to have a separate transmission system to commercialize one or small electric vehicles that do not emit harmful exhaust gas to the human body in a hilly domestic terrain.

In the reality that the number of single-person households is increasing, the increase of personal transportation means can be predicted, and for this reason, commercialization of small electric vehicles, which are the form of personal transportation means, is necessary. In this study, we propose a new structure of CVT system that can be applied to small electric drive vehicles. Based on this, the proposed CVT system using spring was manufactured and the dynamometer test was performed by installing the CVT using spring in a small electric vehicle. The dynamometer test results showed that the power performance was improved.

2. CVT System using Spring

The proposed model of the CVT system for small electric vehicles is like Figure 1. The spring is installed in the driving pulley and driven pulley. The proposed power transmission medium of the CVT system is V-belt. The power transmission in small vehicles can be fully powered by using V-belt. The proposed CVT system model is a form of overcoming the tension of the spring and performing shifting to reduce the load generated by the hill when a small electric vehicle drives the hill and to increase the driving torque. (a) of Figure 1 is the driving mode of the flat road, and (b) is the driving mode of the hill[1].



(a) driving mode at plate (b) driving mode at gradient

Figure 1. CVT System model using spring

The proposed CVT system is a structure that increases the torque by changing the belt pitch radius to increase the torque by itself when climbing the hill. In addition, the speed control device can be operated by the will of the driver to adjust the speed change ratio. Tension T acts on both sides of the V-belt in a force acting on the V-belt, which is a power transmission medium, and reaction R occurs in a vertical direction of the V-belt surface. The tensile force S by the spring mounted on pulley generates in the CVT and the power by the reaction force R and spring tensile force S are combined and the frictional force is occurred. The size of the frictional force actuating on the incline of the V- belt is as follows.

$$\mathrm{F} = 2\mu(\mathrm{R} + \mathrm{S} \cdot \cos\frac{\alpha}{2}) \tag{1}$$

Moreover, the relational expression of the tension T, the reaction force R and spring tension S by belt tension can be obtained from the balance of the force.

$$\mathrm{T} = 2(\mathrm{R} \cdot \mu \cdot \cos\frac{\propto}{2} + S \cdot \mu cos^2\frac{\propto}{2} + R \cdot sin\frac{\alpha}{2}) \tag{2}$$

The equations (1) and (2) are equations that must be applied when assembling components of a CVT system using a spring.

3. Manufacturing a prototype and installing in a small electric vehicle

In the prototype manufacture of the CVT system using spring, if the drive motor and transmission housing are arranged serially, the length of the transmission whole lengthens and it can come out from the vehicle body. For this reason, the drive motor is placed on the transmission housing in parallel, and the result of the production of the prototype with the drive motor and pulley in parallel is the same as Figure 2.

Figure 2. CVT System model using spring

The result of attaching the prototype of the CVT system using the spring produced to the small electric vehicle is the same as Figure 3. The small electric vehicle used can be used for the disabled person, and it is the form which can be used as the general small electric vehicle. According to need, the chair of operator can be arranged. And the speed control is included of the throttle locating in handle. The motor of 24V, 24A, 400W, and 6.8kg_f −cm were used for small electric vehicles. The constant of the spring mounted on the driving pulley and the follower in the CVT system using the applied spring was 2.8kg_f/cm the belt length was 530mm, the driving pulley and the driven pulley size were 110mm, and the groove angle between the driving pulley and the driven pulley was 10 °.

Figure 3. Small electric vehicle equipped CVT system using spring

4. Dynamometer test

The specifications of the dynamometer used in the test were shown in Table 1

Table 1. Specification of dynamometer

tem	Spec.
Frame	- Size(W × D × H) : 2,620 × 1,550 × 650 mm
Roller	- Size : 500Φ × 1,000 mm - Inertia Weight : 180.13 kg - Surface : Nulling, Anodizing
Motor	- Type : AC - Power : 30 kW - Rated Current : 113 A - Max. Torque : 573 N·m - Max. Speed : 3,200 r/min
Torque Sensor	- Output Signal : 30 kHz ~ 90 kHz(60 kHz / Norm) - Measurement Range : 1,000 N·m - Accuracy : 0.05 % / Full Scale - Max. Speed : 10,000 r/min

	- NI cRIO-9073 : 8-Slot Integrated 266 MHz Real-Time Ctrlr, 2M Gate FPGA
DAQ	- NI cRIO-9203 : ±20 mA, 200 kS/s, 16-bit AI Module - NI cRIO-9239 : ±10 V, 50 kS/s/Ch, 24-bit, Ch-Ch Isolated AI Module - NI cRIO-9225 : 300 Vrms, 50 kS/s/Ch, 24-bit - NI cRIO-9227 : current input, 5 Amp, ISO, 50 k, 24-bit - NI cRIO-9213 : TC, 24-bit C Series Module
Power Analyzer	- Basic Power Accuracy (50/60 Hz) : 0.1 % of Reading + 0.1 % of Range - Internal Current Range : 0.5 / 1 / 2 / 5 / 10 / 20 /40 A - Internal Voltage Range : 15 / 30 / 60 / 100 / 160 / 300 / 600 / 1000 V

The figure of installing a small electric vehicle equipped with a CVT system using spring in a dynamometer is the same as Figure 4.

Figure 4. Small electric vehicle on the dynamometer

In order to evaluate the performance of the proposed model, the test was conducted by comparing the case of the CVT device with the case of the motor directly connecting the driving wheel. The results of the dynamometer test are the same as Table 2.

Table 2. Results of dynamometer test

	direct trans.	CVT using spring
max. velocity(km/h)	7.91	10.41
5km/h reaching time(s)	1.6	1.5
climbing performance max. angle(°)	9.21	10.30

As shown in the dynamometer test results of Table 2, it was confirmed that the maximum speed, acceleration performance, and climbing performance of small electric vehicles equipped with a CVT system using spring were improved. The average value of the measurement of the maximum speed, the arrival time and the climbing performance was measured by using the full axel of the vehicle when measuring the maximum speed and the arrival time, and the maximum climbing angle was calculated by using the following equation (3). The values described are also average after three tests.

$$Max.climbing\ angle = \frac{360}{2\pi} \times sin^{-1}(\frac{P-P_1}{Mg}) \tag{3}$$

where,

P : measured driving force[N]

P_1 : road load at set speed[N]

M : driver weight + empty car weight[kg]

g : gravitational acceleration[m/sec^2]

Table 3. Data of max. climbing angle

	Time(sec)	driving force(N)	road load (N)
direct trans.	39.64	225.09	12.48
CVT using spring	39.21	252.43	9.17

5. Conclusion

In order to commercialize and popularize small electric vehicles that can be applied as personal transportation in many hilly domestic terrains, we proposed a new structure of a CVT system for small electric vehicles. The proposed system was designed and the dynamometer test was performed by installing the proposed system in a small electric vehicle. In order to compare and evaluate the results of the dynamometer test, the following conclusions were obtained from the test of the direct connection between the electric motor and the driving wheel in the same small electric vehicle and the installation of the CVT using the spring proposed in this study.

1) The maximum speed performance was improved by 31.6%.
2) The time to reach 5km/hr, or acceleration performance, was improved by 7%.
3) The climbing performance improved by 11.8%.
4) The motor and housing should be arranged in parallel when the proposed model is applied to the transmission system of small electric vehicles.

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