Study on Shifting Performance of Electronically Controlled Continuously Variable Transmission (E-CVT)

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Abstract: - Due to inherent mechanism constraints, general Continuously Variable Transmission (hereinafter referred as CVT) of scooter motorcycle often needs to wear centrifugal rollers and movable flange, and the transmission efficiency is low when at low speed or low torque. To improve these problems, it is required to coordinate with internal combustion engine power output characteristics and adjust reduction ratio to show most efficient power output. This paper aims at designing an Electronically Controlled Continuously Variable Transmission (hereinafter referred as E-CVT) to obtain input shaft speed, vehicle speed, and output shaft speed signals through various sensors, and coordinated with internal combustion engine power output performance to calculate instant target reduction ratio. Signals are sent out through fuzzy controller to control stepping motor to rotate roller ball guide bolt to change actual reduction ratio, and together with various instant speeds to determine shifting timing to achieve automatic shifting, so that internal combustion engine can be maintained at higher performance output, and in such doing, loss while power transmission can be reduced and energy efficiency can be improved. This study uses fuzzy controller to control electric cylinder to achieve the purpose of changing reduction ratio, and together with power source motor to establish a two-dimensional reduction ratio look-up chart, such that appropriate reduction ratio can be obtained based on actual power source output characteristics and operational intent of the driver to achieve the purpose of automatic shifting.

Key-Words: - Scooter Motorcycle; Electronically Controlled Continuously Variable Transmission (E-CVT); Shifting Performance

1 Introduction

Today's internal combustion engine technology is already quite mature, but matched mechanical transmission system is still unable to reach a higher transfer efficiency, such as maximum steady-state transmission efficiency of conventional CVT is only about 80%, compared to other similar mechanisms such as V-belt driver, transmission efficiency of conventional CVT is quite lower, this is the main factor which causes lowered motorcycle’s overall performance and energy consumption efficiency. This study applies to scooter motorcycles with electronic type CVT. Through combining the advantages of the control capability of E-CVT and the mechanism of conventional mechanical CVT, the shortcomings of conventional mechanical CVT can be improved and capable of actively controlling the increase and decrease of reduction ratio, and also can allow internal combustion engine keeping on a better running point, so that internal combustion engine can be maintained on running at a better operating point, and the motorcycle can be kept in a state of low fuel consumption and low emission while driving, and can reduce gasoline consumption and air pollution. The E-CVT of this study makes use of combined design of electric cylinder as active component of transmission system. Hope to be able to maintain the internal combustion engine running at a better operating point [1], as shown in Figure 1. Reduction ratio will be actively changed by matching changes of scooter motorcycle’s driving resistance. Research method will focus on designing an easy-to-operate and low-cost transmission system, control strategy of E-CVT, mechanism design, and matching of power system, as well as establishing a E-CVT test platform and use it to simulate under a fixed internal combustion engine speed to observe response changes of E-CVT controlled by electric cylinder through using new controller.
Fig. 1 Characteristics curve of internal combustion engine (ωe: Engine Speed, Te: Engine Torque) [1]

2 E-CVT Automatic Shifting Process

Reduction ratio of transmission device is defined as the ratio of the speed of main driving wheel to the speed of driven wheel, i.e. in equation (1)

\[ i = \frac{n_{DR}}{n_{DN}} \quad (1) \]

where \( n_{DR} \) is main driving wheel input speed, \( n_{DN} \) is driven wheel output speed.

You can also use pitch radius ratio of main driving wheel to driven wheel to represent. When driven wheel is at maximum pitch radius \( (R_{DN_{\text{max}}}) \) and main driving wheel is at minimum pitch radius \( (R_{DR_{\text{min}}}) \), get maximum reduction ratio \( (i_{\text{max}}) \), as in equation (2):

\[ i_{\text{max}} = \frac{R_{DN_{\text{max}}}}{R_{DR_{\text{min}}}} \quad (2) \]

When main driving wheel is at maximum pitch radius \( (R_{DR_{\text{max}}}) \) and driven wheel is at minimum pitch radius \( (R_{DN_{\text{min}}}) \), get minimum reduction ratio \( (i_{\text{min}}) \), as in equation (3):

\[ i_{\text{min}} = \frac{R_{DN_{\text{min}}}}{R_{DR_{\text{max}}}} \quad (3) \]

Target reduction ratio is defined as shown in equation (4):

\[ \begin{cases} i_{\text{max}} \quad \frac{i_{\text{max}}}{n_{DR_{\text{max}}}} = \frac{n_{DN_{\text{min}}}}{n_{DN_{\text{min}}}} \\ i_{\text{min}} \quad \frac{i_{\text{min}}}{n_{DR_{\text{min}}}} = \frac{n_{DR_{\text{min}}}}{n_{DN_{\text{max}}}} \end{cases} \]

When the power source target input speed is determined, the target reduction ratio can be easily determined according to driver’s intention and actual output speed. Similar to the situation of manual gearbox, both the motorcycle’s driving condition and driver’s operational intention are of a dynamic change process. But CVT transmission system is not operated in a fixed matching pattern or explicitly switched from one pattern to another pattern, rather according to vehicle’s driving conditions and driver’s operational intention and on the basis of a typical matching, a matching pattern with best combined performance indicators is generated in accordance with certain rule. In order to ensure motorcycle is driving with different speeds under any road resistance condition, and maintain an operating point desired by power source [2], a two dimensional reduction ratio look-up chart regarding input speed and output speed of continuously variable gearbox transmission device can be confirmed according to target reduction ratio formula, as shown in Figure 2. Because when input speed falls in the range of below 1000 rpm, resulted friction and big vibration will cause overall system unstable while the overall system is in operation, collected data in this range would have larger errors, so take the input speed 1000 rpm to 1800 rpm of motor speed as input speed range, output speed range is 0 rpm to 600 rpm, while the corresponding reduction ratio range is from the largest reduction ratio 10 to the smallest reduction ratio 3.

Fig. 2 Target reduction ratio look-up chart
3 Experiment Platform

This study adopts a 2.2kW variable frequency AC electric motor as internal combustion engine input power source of simulated scooter motorcycle system to transfer power to CVT. The system is configured with a electric cylinder as active component, except removed clutch cover and brake pad, the remaining conventional

Mechanical CVT is kept to maintain the existing motorcycle mechanisms in a motorcycle, torque meter and magnetic powder brake are connected onto the output shaft of CVT and used to provide load, the physical installation of the platform is shown in Figure 3. The main objective of the system is to be designed as capable of providing high efficient power transmission and simple system configuration, and being installed on a real vehicle.

Fig. 3 E-CVT platform physical installation

This section is primarily in exploring the concept design of E-CVT. Based on previous theoretical introduction and analysis, it is clearly understood that the general widely used rubber belt-type CVT in scooter motorcycles is mainly by means of axial thrust force arising from rotating movement and geometrical effect of centrifugal rollers installed in driving-side radial wheel disk, and opposite axial thrust force arising from feedback driving resistance force of torque cam installed in driven-side radial wheel disk, and through mutual regulation of these two axial thrust forces to complete variable speed ratio control. The main purpose of this study aims at designing and developing an E-CVT suitable for applying in scooter motorcycles. It improves conventional mechanical passive mechanism by using electronic servo-control method to control shifting mechanism, so as to achieve the function of actively controlled shifting. The conceptual sketch of mechanism design is shown in Figure 4[3]. This study adopts LabVIEW software as control and monitoring software. In terms of data acquisition, this software has a very high convenience and can provide user with the function of issuing a number of instructions at the same time through its data acquisition system for his use [4]

Fig. 4 Conceptual sketch of mechanism design [3]

4 Experimental Results

Advantages of CVT shifting can reach smooth and continuous shifting, and makes use of power source output characteristics to achieve changes under different patterns. Using motor as power source, the motor torque test diagram is shown as in Figure 5.

Without considering the transfer losses of speed and of torque, the changes of motor torque corresponding to speed under different shifts are shown as in Figure 6. When the number of shifts becomes more, the curve connected by maximum power point of each shift will be closer to maximum power curve. Because CVT has the characteristic of holding infinite shifts, it is therefore capable of closing to the ideal power, allowing CVT to maintain power source working in the maximum power point at any time, so that power source can fully play its power to achieve improved vehicle dynamics.

Fig. 5 Motor torque test diagram
From Figure 7, it can be seen that under the circumstance of fixing the reduction ratio at relationship between speed input and output speed, when at maximum reduction ratio, the input speed climbs up from 1000 rpm to 1800 rpm, while the corresponding output speed climbs up from 100 rpm to 180 rpm, the slope is larger and the range of output speed is smaller. When reduction ratio is smaller, input speed climbs up from 1000 rpm to 1800 rpm, while the corresponding output speed climbs up from 330 rpm to 600 rpm, the slope is gentler and the range of output speed is significantly larger. When reduction ratio gradually decreases, but the range of variable speed will gradually expand.

When input speed immediately drops down from 1800 rpm to 1000 rpm, through about 16 seconds, the output speed will reach the maximum reduction ratio of 100 rpm, as shown in Figure 10. The changes of target reduction ratio and actual reduction ratio are shown as in Figure 11.
5 Conclusion

This experiment adopts E-CVT of scooter motorcycle as main experiment subject, uses new controller to control actual reduction ratios, and matches with power characteristics of power source according to the needs of different patterns, to generate a two-dimensional look-up chart for individual reduction ratios, so that appropriate reduction ratio can be matched out based on actual input speed and output speed from power source to achieve automatic shifting purpose. This study also focuses on developing a E-CVT suitable for real motorcycle applications, improves feasibility of real vehicle applications, and reduces the cost of R&D expenditures. According to actual experimental results of E-CVT in this study, derived the following conclusions:

(1) This study has established an E-CVT experiment platform capable of executing automatic shifting, control instructions can be transmitted and various output data can be captured through a human-machine interface, and achieved the purpose of actively controlling changes of reduction ratios.

(2) Coordinated with a power source motor, this study established a two-dimensional reduction ratio look-up chart, capable of achieving the purpose of automatic shifting by matching out appropriate reduction ratio in accordance with actual power output characteristics of the power source and driver’s operational intention. The average error between actual reduction ratio and target reduction ratio is about within the range of 10%. There is a time-delay relationship while in using detected input speed and output speed of CVT to calculate reduction ratio, so that a slight oscillation exits before stabilization when using a computer to look-up table.

(3) The E-CVT developed in this study can be easily installed on real vehicle gearbox body, and effectively lowers the requirement for modifying the real vehicle, thus reduces the cost consumption of mass production.

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