DEVELOPMENT OF A CONTINUOUSLY VARIABLE-SPEED TRANSMISSION FOR AGRICULTURAL TRACTOR +

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ABSTRACT

This study was carried out to develop a continuously variable-speed transmission(CVT) for agricultural tractor. A full-toroidal CVT mechanism with four discs and six rollers was selected as a device for changing speed ratio continuously.

In the step of system layout design, the sizes of roller cylinders and end-load cylinder, which were critical factors for controlling the variator, were designed. Also the control pressure range was designed to limit the contact pressure of variator. In order to make the maximum speed of vehicle as 30km/h, the planetary gear and the six pairs of gears were designed. Also the hydraulic clutch, silent chain, hydraulic manifold and electronic controller were designed. After the design, a prototype with CVT controller was developed and tested. The speed of vehicle was changed continuously to the speed set by driver and the settling time was about 0.52 second at the step-response test (reduction ratio of variator, from 2.0 to 1.0), which was acceptable as a response time for working with tractor.

Key Word : Tractor, Transmission, CVT, Speed Control, Load Control

INTRODUCTION

Farmers in Korea are getting older and thus the need for comfortable farming and economical farming has been increased along with high working efficiency and adaptability of farming facilities in various type of works.

Agricultural tractor is the main farming tool, so many companies have made efforts to develop more comfortable and efficient tractor for farming to meet the farmer's demand

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Recently, small tractor with HST(Hydrostatic Transmission) has been used not only for garden but for the farm in Japan and demand of the tractor with power-shift transmission above 60 PTO HP has been increasing. Although the HST has advantage in step-less speeds, the efficiency is compromised. Power-shift transmission has steps in speeds as disadvantage.

Therefore, efficient stepless transmission is required for farming tractor and continuously variable speed transmission with toroidal system is considered as an alternative for this requirement.

The CVT prototype with four discs and six rollers was developed and in order to control the mechanism, an electro-hydraulic controller was developed. Then the control performance of the prototype was tested.

MATERIALS AND METHODS

1. Design of the CVT mechanism

For the development of CVT prototype, some specifications were decided and the basic model was selected.

Table 1. shows the specification of engine, transmission and tractor body of CVT prototype developed.

Table 1. Specification of CVT Prototype

	Content	Specifications
Engine	No. of Cylinder Displacement Horsepower	4 2311cc 35PS/2500rpm
Transmission	Speed Range Shift Method Shuttle type	-12km/h ~ 30km/h CVT and Mode Change By manual lever
Tractor Body	Wheel base Front Rear Vehicle Weight	1,700 mm 1,100 mm 1,100 mm 1,600kg

Generally the power train of CVT consists of input shaft, output shaft, variator and summarizer. Fig. 1 shows a schematic diagram of CVT.

In Fig. 1, variator has a function for changing speed ratio continuously. Full-toroidal mechanism was selected as a variator. This mechanism has a merit of easy construction and no need to use a torque converter as a starting device.

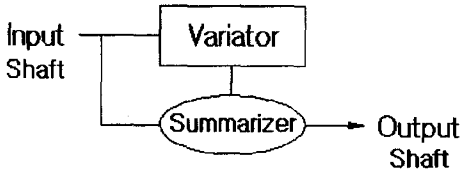

Fig. 1. A schematic diagram of CVT

1.1. Variator

Fig. 2 shows 3-D drawing of CVT variator. The variator has four discs and six rollers. Between input discs and output discs, six rollers rotate and they transfer the power from engine to wheel.

The hardness of them must be more than that of bearing material and final polishing on the contact surface is required

To change the speed ratio with rollers, hydraulic cylinders were connected to roller shafts and end-load disc.

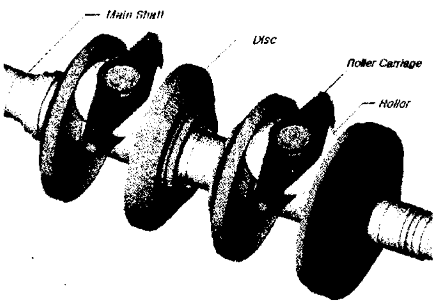

Fig. 2. 3-D drawing of CVT variator

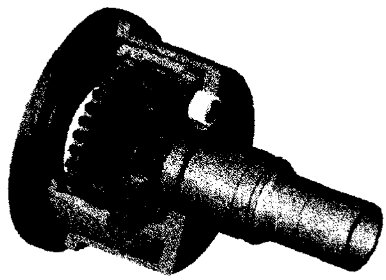

Fig. 3. Planetary gear of CVT

1.2. Planetary Gear

Fig. 3 shows planetary gear developed for CVT. The sun gear was connected to variator shaft and the career was connected to the engine shaft.

The rotational speed of ring gear connected to output shaft depends on the speed of sun gear and ring gear. Thus, if the rotational speed of engine shaft is constant, vehicle speed depends on the speed ratio of variator.

1.3. Hydraulic Clutch

Three hydraulic clutches were designed in order to manage the separated range of speed, as the variator does not cover the full range of vehicle speed.

The Clutches consist of a high hydraulic pressure line, a lubrication line, some friction plates and cylinder.

1.4. End-load Cylinder

The traction condition at variator depends on the rotation of discs and the pressure by end-load cylinder

The size of end-load cylinder was designed according to the size of roller cylinder, traction coefficient and the size of shaft.

The relation of each size and traction coefficient is shown at Eq. (1).

Because D_o, D_i and the roller caster angle in Eq. (1) are decided by strength analysis, finally D_p must be designed according to traction coefficient.

$$\mu = \frac{3\cos\beta \cdot D_p^2}{2(D_o^2 - D_i^2)} \quad \cdots\cdots \quad \text{Eq. (1)}$$

Where, μ : Traction coefficient

D_p : Diameter of roller cylinder

D_o : Diameter of end-load cylinder

D_i : Diameter of end-load shaft

β : Roller caster angle

Because the pressure in the end-load cylinder isn't sufficient for traction when the engine starts, a plate spring was installed in end-load cylinder.

1.5. System Layout

After the design of the essential elements, we arranged optimally the shafts, gears, variator and other parts in transmission case.

Fig. 4 shows a system layout of CVT transmission.

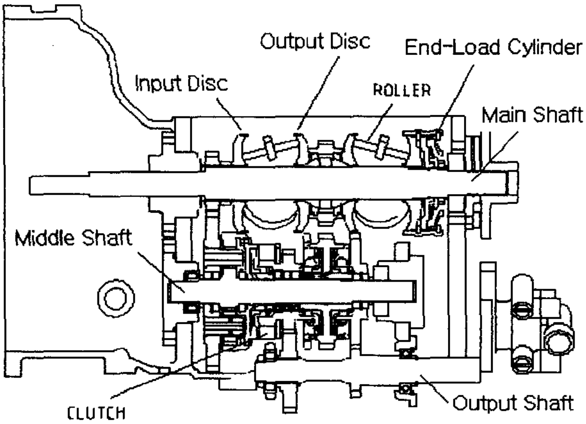

Fig. 4. Layout of CVT mechanism

2. CVT Controller

A controller for controlling the CVT mechanism consists of a measuring system, hydraulic system and a main computer. Fig. 5 shows the layout of CVT controller.

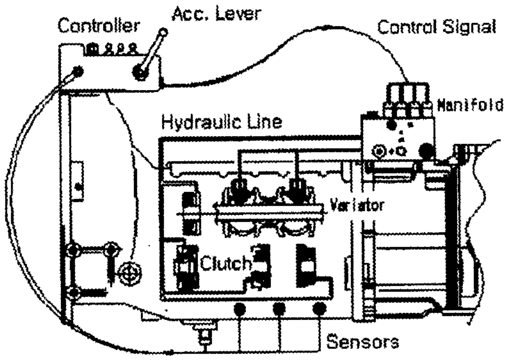

Fig. 5. CVT Controller Layout

2.1. Sensors

The measuring system of CVT controller consists of three rotational speed sensors, lever sensors, temperature sensor and two pressure sensors.

In order to calculate the reduction ratio of variator (RV), the rotational speeds of engine shaft and variator shaft were measured with two rotational speed sensors. And other rotational speed sensor was used for measuring the vehicle speed. Magnetic pickup and signal conditioning circuit were developed as a rotational speed sensor.

When a driver orders drive condition with levers, lever sensors and some switches were used in order to measure that signals.

Two potentiometers were installed at dashboard as an accelerator lever sensor and a speed setting lever sensor. A shift lever with four electric switches was used for the acquisition of driver's order. In addition, brake switch was installed below brake pedal.

For observation of the traction oil condition, a temperature sensor was installed in the transmission case and two pressure sensors were installed on the hydraulic line between roller cylinder pump and proportional valve.

2.2. Hydraulic System

To control mode clutches and variator, an electro-hydraulic system was developed. Hydraulic system consists of hydraulic manifold, roller cylinder, clutches, pipes and electronic circuits for hydraulic valves. Fig. 6 shows a hydraulic control circuit for the CVT controller.

In Fig. 6, PCV1 and PCV2 are the proportional pressure control valves, DV1, DV2, DV3, DV6 are On-Off solenoid valves for hydraulic clutches. Hydraulic circuit has two pressure lines. One is a high-pressure line for controlling the double-acting roller cylinder and the other is low-pressure line for maintaining soft-fill pressure. Also the low-pressure line is used to lubricate the traction point. DV5 valve controls a double-acting cylinder of shuttle mechanism.

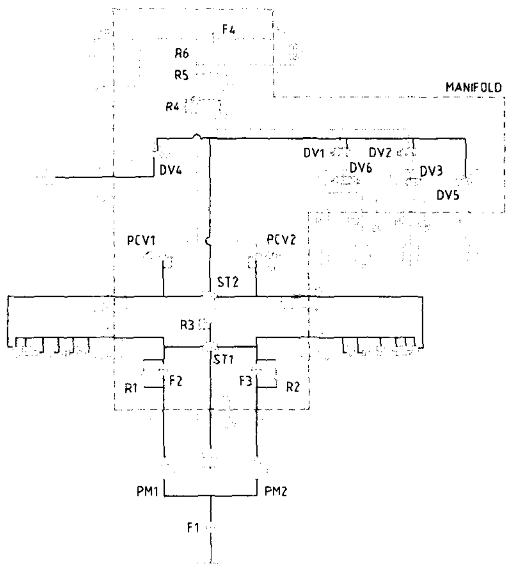

Fig. 6. CVT Hydraulic Control Circuit

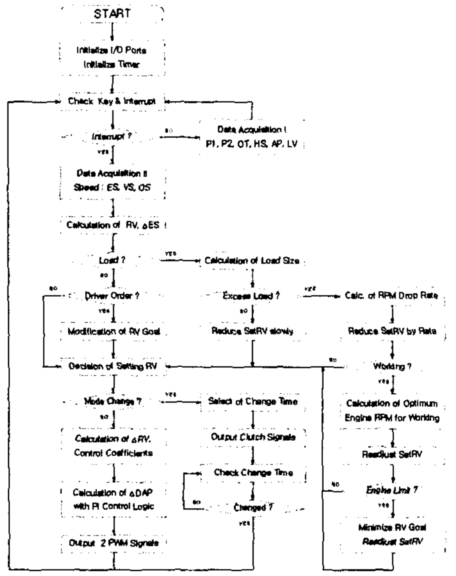

Fig. 7. Control Algorithm for CVT

2.3. CVT Control Algorithm

Fig. 7 shows a control algorithm for CVT controller. In Fig. 7 control algorithm includes main algorithm, load response algorithm and mode change algorithm.

The main algorithm has initialization routine, data acquisition routine, valve control routine and a routine for changing the object reduction ratio of variator. Each routine is selected one by one in main algorithm.

The routine for changing the object RV calculates the quantity of load with the rotational speed drop of engine and decides the control signals for the mode change and proportional control valve. This routine was connected to load response routine.

The basic control algorithm for the RV includes PI control algorithm with the coefficient table. The coefficient table has some coefficients selected according to each modes and RV range. Coefficients were decided through laboratory test and field test.

When the excessive load appears, the mode change algorithm is selected and the speed of vehicle decreases rapidly.

3. Performance Test

To evaluate the developed prototype of CVT, the speed changing test and step response test were carried out. For the step response test, the test range of RV was decided from 2.0 to 1.0. Also the field test with plow was carried out and the response to load generated by field working was tested.

RESULTS AND DISCUSSION

Change of the Vehicle Speed

To evaluate the basic function of CVT, speed-changing test was carried out. The rotational speed of engine was fixed with 1000 rpm.

Fig. 8 shows the result of speed-changing test with CVT tractor. The straight lines are the theoretical speed and the target RV. And other lines are the result of test. The control error was within 0.1 RV and when the speed was constant, the error became smaller than 0.05. At the full range of speed, the setting speed was controlled very well.

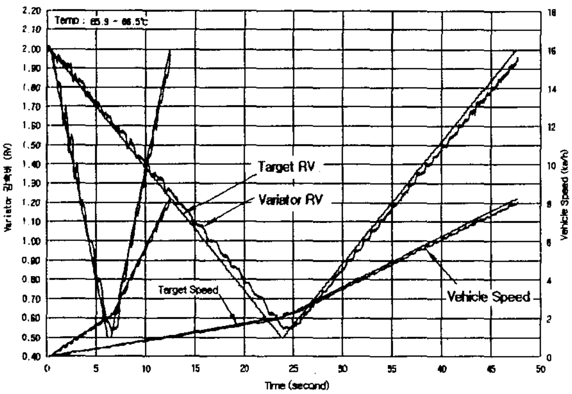

Fig. 8. Speed Curve of CVT Tractor

Step Response Test

To evaluate the control performance of CVT controller, step response test for reduction ratio of variator was carried out.

Fig. 9 shows the result of step response test when the setting RV value was changed from 2.0 to 1.0. At the graph, the rise time was 0.33 second and the settling time was 0.52 second and there was no overshoot.

The settling time in this test was very small value. Thus the CVT tractor could be controlled very well.

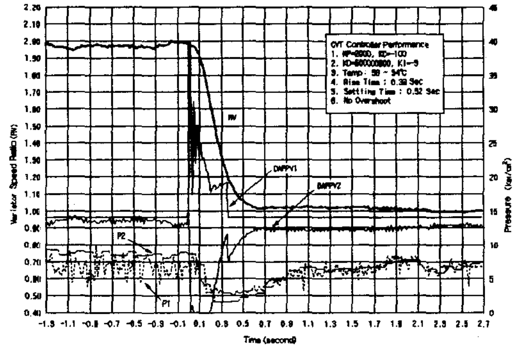

Fig. 9. Step Response [RV, 2.0->1.0]

Working Performance

Fig. 10 shows the result of the fields test. When the traction load increase, controller detects the quantity of load and lowers the RV. Therefore the load decreases and the speed are recovered. CVT tractor was controlled well by load response algorithm.

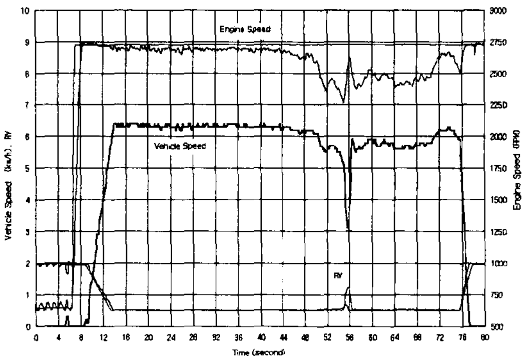

Fig. 10. A result of field test (plowing)

CONCLUSIONS

This study was carried out to develop a CVT applicable to agricultural tractor. The full-toroidal type was selected for the tractor CVT mechanism.

In the step of system layout design, the sizes of roller cylinders and end-load cylinder were designed. In order to make the maximum speed of vehicle 30km/h, the planetary gear and the six pairs of gears were designed. Also, the hydraulic clutch, silent chain, hydraulic manifold and electronic controller were designed. After the design, a prototype with CVT controller was developed and tested.

The speeds set by driver were changed continuously in the full range of speed and the settling time was 0.52 Second at the step response test (reduction ratio of variator, from 2.0 to 1.0). In this study, the above value was acceptable as a quick response time for working with tractor.

REFERENCES

1. Fellows, T.G. and C.J. Greenwood, 1991. The design and development of an experimental traction drive CVT for 2.0 litre FWD passenger car. SAE paper 910408.
2. Hamrock, B. J., 1994. Fundamentals of film lubrication. McGraw-Hill, Inc.
3. Patterson, M. 1996. The full-toroidal variator in theory and practice. Proceedings of the International Conference on Continuously Variable Transmission, 95-100.
4. Wicke, V., C.J. Brace, and N.D. Vaughan, 1996. The potential for simulation of drivability of CVT vehicles. SAE paper 00PC-218.
5. James, I.B. and N.D. Vaughan, 1996. Design and component matching of a pressure control circuit. SAE paper 961854.