Shifting Speed and Belt Behavior of Model CVT (Continuously Variable Transmission) with Push and Pull Type V-belt Driven on Semi-Transparent Pulleys

Influence of Stiffness of V-belt in Clamping Direction

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Keywords: CVT (Continuously Variable Transmission), V-belts, Shifting Speed, Deformation.

Abstract: The purpose of this study is to investigate influence of the stiffness of V-belt in clamping direction on shifting speed of V-belt type CVT (Continuously Variable Transmission). Model CVT with push and pull type V-belt was prepared with semi-transparent pulleys made of epoxy resin in order to observe the belt behaviour in the pulley groove. The stiffness of the belt in clamping direction was changed to investigate the influence on the shifting speed in which the cross sections of belts were reduced as the alternative types of belts. At the case where the belt pitch radius was increased, the behaviour of elements of the push type V-belt in the pulley groove indicated that the remarkable radial slip between the element and pulley was not occurred. It was suggested that the pitch radius of the belt entering into pulley groove was depended on the deformation of the belt in compression in clamping direction in pulley groove. It was shown that the shifting speed was increased by reducing the stiffness of belts in clamping direction regardless of the belt type.

1 INTRODUCTION

The market share of vehicles with V-belt type CVT is expected to keep growing in the future because they achieve a higher fuel economy than vehicles with other transmissions (T.Fujii, 2008). CVTs have advantages capable of maintaining proper rotational speed at all time in terms of engine efficiency by changing speed ratio flexibly and continuously.

An example of V-belt type CVT setup is shown in Figure 1. The V-belt type CVT is composed of a driving V-pulley, a driven V-pulley and a V-belt. These V-belts are classified into two types, push type V-belt and pull type V-belt. The driving V-pulley and the driven V-pulley both are usually composed of a movable pulley and a fixed pulley. The V-belts are clamped between the movable pulley and the fixed pulley in order to generate traction by frictional force. Clamping force is usually applied onto belt by oil pressure generated by oil pump and others. On changing balance of clamping forces between the driving movable V-pulley and the driven movable V-pulley, the shift change sets in.

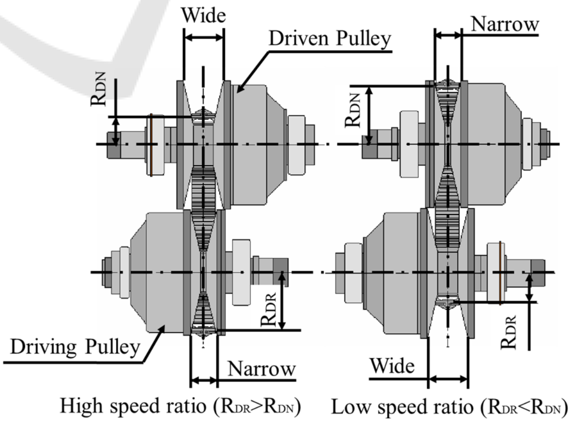

Figure 1: V-belt type CVT setup.

To keep safety operation and provide practical shifting speed clamping force is often excessive over the reasonable force. Oil pump loss for applying clamping force onto belt often accounts for approxi-

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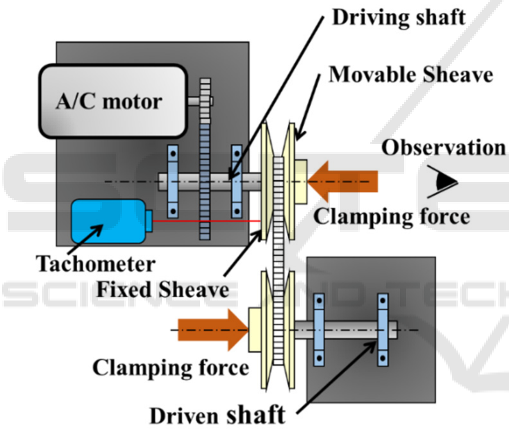
mately 60% of loss in the whole CVT units. Therefore, the clamping force should be reduced to increase efficiencies of CVTs. The motivation of the work is to develop new CVT with high efficiencies and response.

The purpose of this study is to investigate the influence of stiffness of V-belt in clamping direction on shifting speed of V-belt type CVT in order to discuss the mechanical design to determine appropriate clamping force.

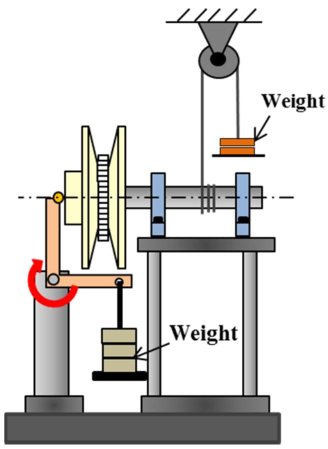
2 TEST METHOD

2.1 Test Setup

The model CVT was developed with light V-belt and semi-transparent epoxy resin pulleys in which the belt behaviour in pulley groove was able to be observed. Figure 2(a)(b) shows the illustration of model CVT test apparatus used for measurements.



(a) Top view



(b) Front view around driven pulley

Figure 2: Schematic view of test apparatus of model CVT.

The test apparatus was set up with the model CVT unit, the A/C motor, the winch, and the lever. The A/C motor was installed instead of a combustion engine to provide power. The power was transmitted to the driven shaft from the driving shaft through the CVT unit. Driven torque was applied by winding up a weight by a wire on the shaft. Pulley clamping force was also applied onto belt by another weight with levers instead of oil pressure.

2.2 Specimens for Measurements

Pushing type model belts were originally prepared with tentative elements made of acrylic resin and laminated steel rings. Low-stiff push type belts with low-stiff elements were also prepared of which cross sections of the elements were reduced by introducing a flat notch to change the stiffness in clamping direction (Figure 3). For the alternative push type belt, stiffness of the belt was reduced about 30% in clamping direction compared with that of the original belt.

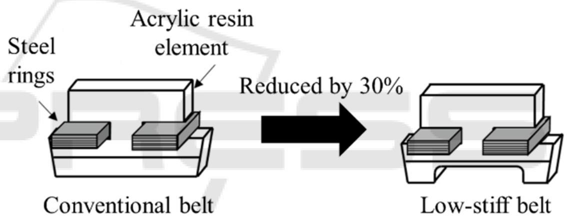


Figure 3: Elements of push type belts.

Pulling type model belts were also prepared made of rubber elastomer and steel cords. Low-stiff pull type belts were also prepared of which cross sections of the belt were reduced by introducing a half circular notch to change the stiffness in clamping direction (Figure 4). For the alternative pull type belt, stiffness of the belt was reduced about 31% in clamping direction compared with that of the original belt.

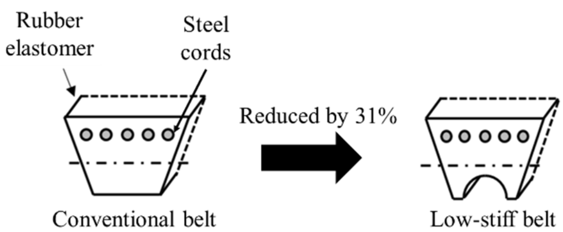


Figure 4: Cross sections of pull type belts.

2.3 Measurement of Shifting Speed

The speed ratio i was defined as the equation (1).

$$i = \frac{R_{DN}}{R_{DR}} = \frac{N_{DR}}{N_{DN}} \quad (1)$$

where, R_{DR}, R_{DN}, N_{DR}, N_{DN} denoted the pitch radius of belt in the driving pulley and in the driven pulley, the rotational speed of the driving shaft and of the driven shaft, respectively.

Table 1 and 2 shows test conditions for push and pull type, respectively. The shifting speed was defined as dR/dt (the variation of belt pith radius per unit of time).

Table 1: Test conditions with push type belt.

	Shift up state (i = 1.25 → 0.8)	Shift down state (i = 0.8 → 1.25)
Rotational speed of driving pulley	20rpm	
Transmitted torque	294Nmm	
Clamping force of driving pulley	186, 206, 225, 245, 265N	147N
Clamping force of driven pulley	147N	186, 206, 225, 245, 265N

Table 2: Test conditions with pull type belt.

	Shift up state (i = 1.25 → 0.8)	Shift down state (i = 0.8 → 1.25)
Rotational speed of driving pulley	20rpm	
Transmitted torque	294Nmm	
Clamping force of driving pulley	186, 206, 225N	118N
Clamping force of driven pulley	118N	186, 206, 225N

The rotational speed of the driving pulley was about 20rpm during experiments. The transmitted torque was also kept constant at 294Nmm. The shifting speed was evaluated by measuring the times required for the belt to change to change the pitch radius associated with i=1.25 to i=0.8 for shifting up and opposite change to shifting down, respectively (Figure 5).

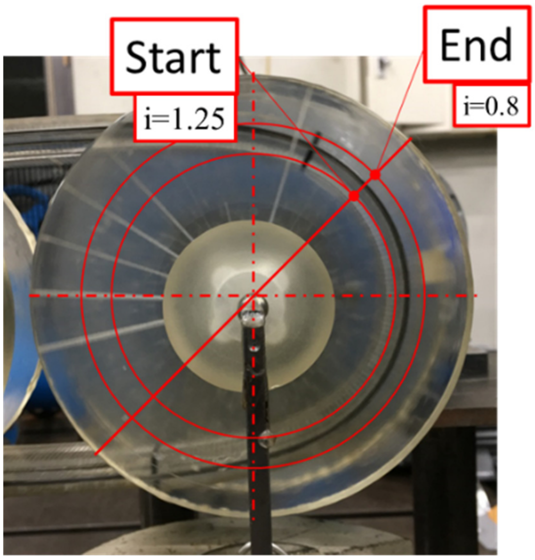


Figure 5: Measurement of shifting speed.

2.4 Measurements of Radial Slip

Figure 6 shows an example of the result of image analysis. To evaluate radial slip between elements in pulley groove and pulley, the behaviour of an element of push type belt in pulley groove was observed by a miniature camera attached onto driven pulley. The radial displacement of the point mark attached on contact surface of the element from initial point was measured as radial slip between element in pulley groove and pulley.

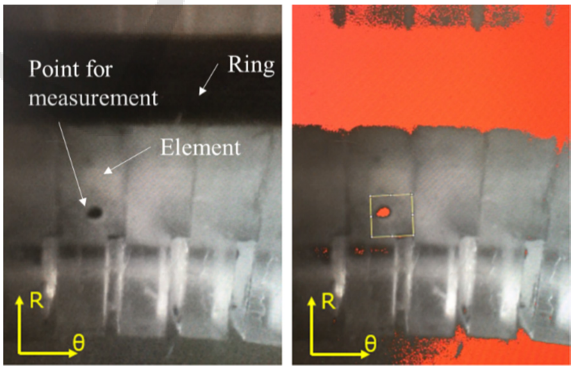
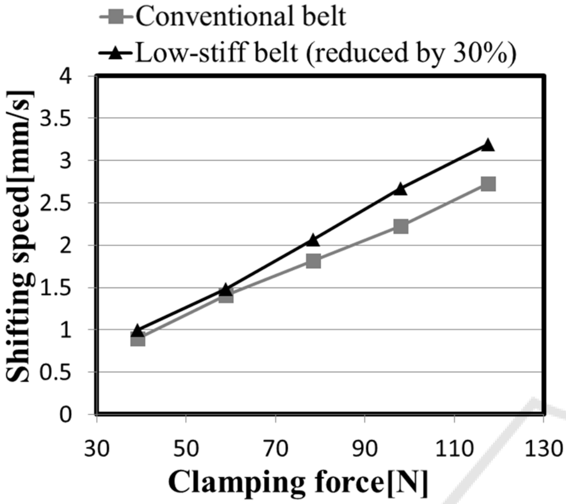


Figure 6: Example of result of image analysis.

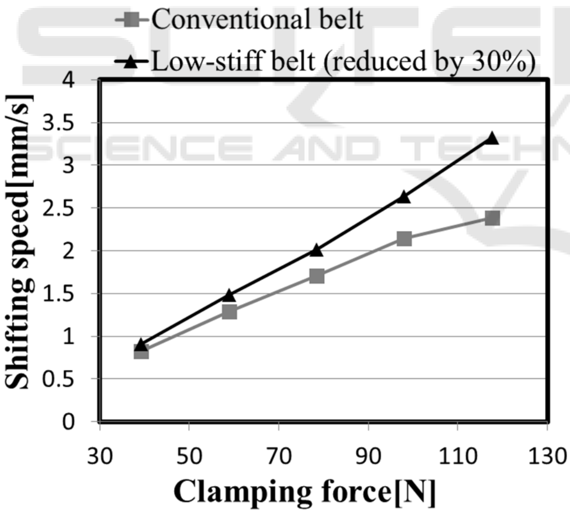
3 RESULTS

Figure 7(a)(b) and Figure 8(a)(b) show the relationship between the shifting speed and clamping force measured with the push type low-stiff belt and the conventional belt. The significant difference was observed in the shifting speed of the push type low-stiff belt and that of the push type conventional belt.

These results showed that reducing the stiffness of belt elements in clamping direction contributed to increase the shifting speed.

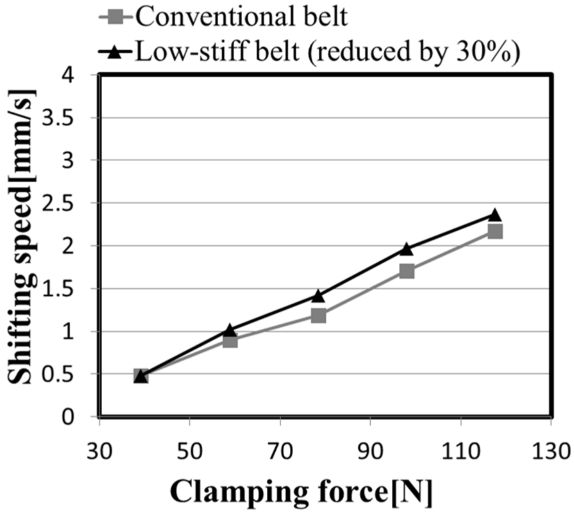


(a) Under shifting up

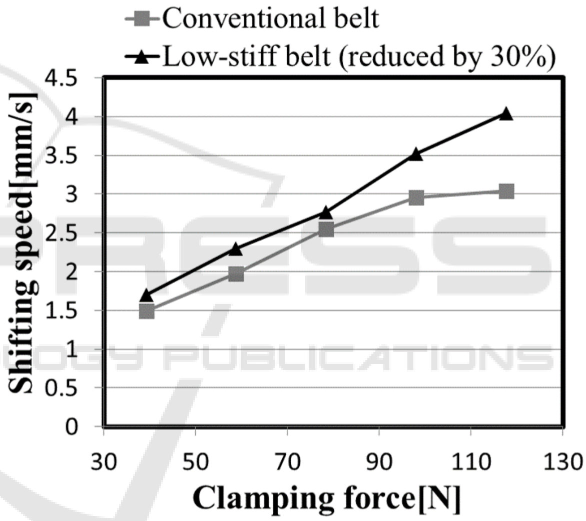


(b) Under shifting down

Figure 7: Relationship between shifting speed and clamping force in push type belt when transmitted torque was almost zero.



(a) Under shifting up

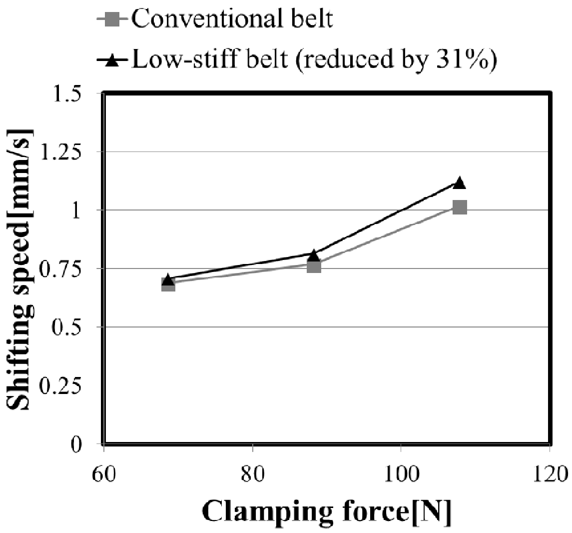


(b) Under shifting down

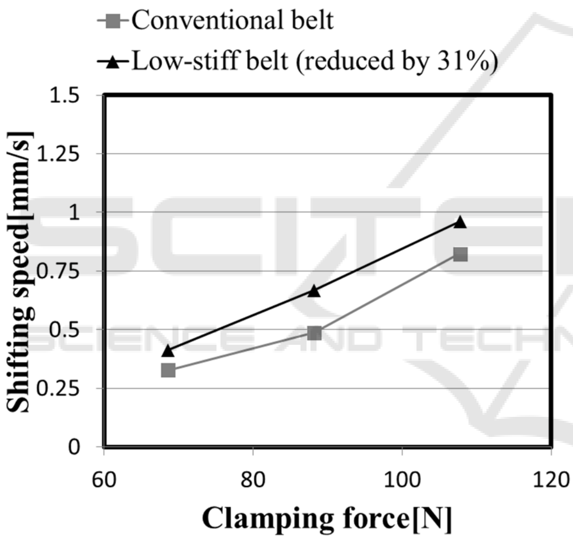
Figure 8: Relationship between shifting speed and clamping force in push type belt when transmitted torque was 294[Nmm].

Figure 9(a)(b) and Figure 10(a)(b) show the relationship between the shifting speed and clamping force measured with the pull type low-stiff belt and the conventional belt. The significant difference was also observed in the shifting speed of the pull type low-stiff belt and that of the pull type conventional belt.

These results showed that reducing the stiffness of belt in clamping direction contributed to increasing the shifting speed, as well as the test results with push type belts.

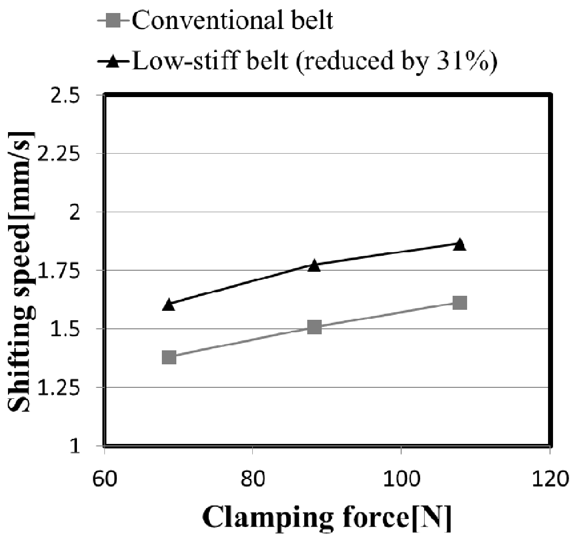


(a) Under shifting up

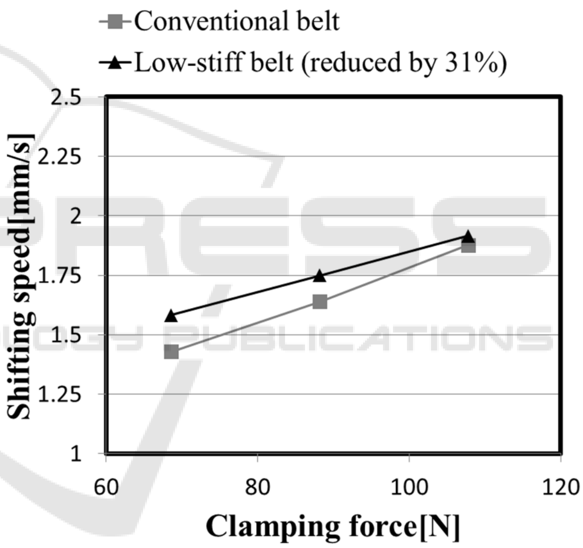


(b) Under shifting down

Figure 9: Relationship between shifting speed and clamping force in pull type belt when transmitted torque was almost zero.



(a) Under shifting up



(b) Under shifting down

Figure 10: Relationship between shifting speed and clamping force in pull type belt when transmitted torque was 294[Nmm].

4 DISCUSSIONS

Figure 11 shows the radial slip between element and pulley at the case where the belt pitch radius was decreased and that at the case where the belt pitch radius was increased, respectively. At the case where the belt pitch radius was decreased, radial slip between element and pulley was remarkably occurred. On the other hand, at the case where the belt pitch radius was increased, radial slip was almost not observed even if shifting state. It was suggested that the belt pitch radius was increased not by slipping between element and pulley but by deformations of elements in clamping direction.

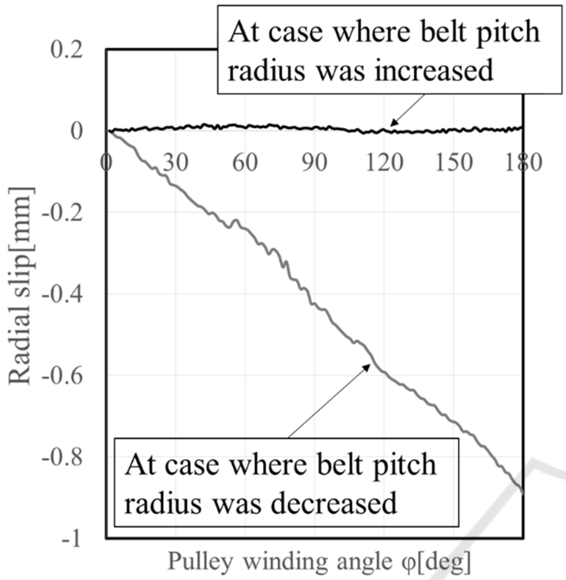
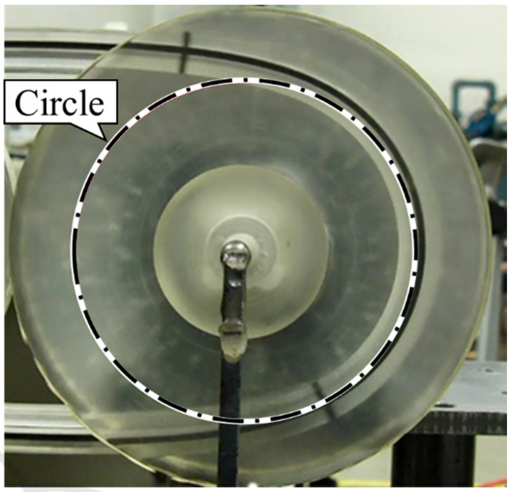


Figure 11: Radial slips between element and pulley for push type belt.

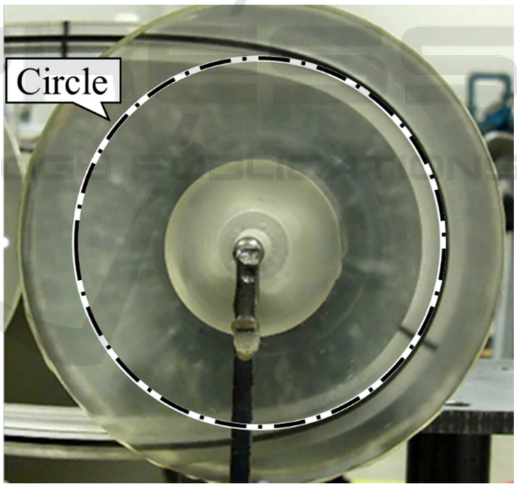
Figure 12(a)(b) and Figure 13(a)(b) show the behaviour of push type belt and pull type belt in pulley groove at the case where the belt pitch radius was increased and that at the case where the belt pitch radius was decreased. Same tendencies were observed on the belt behaviours for push type and pull type belt, as bellow. The belt pitch radius was decreased maintaining complete circle shape by which the belt significantly slipped in pulley groove in the same time (Figure 12(b) and 13(b)). On the other hand, the belt pitch radius was increased as spiral shape by some deformations of the belt in clamping direction in the pulley groove without significant slip (Figure 12(a) and 13(a)).

The belt was deformed in compression in pulley groove by clamping force. At the case where the belt pitch radius was increased, the belt entering into pulley groove should be entered at external position in radial direction because internal sheer force was produced by the difference of the radial locations around the entrance. The difference of the radial locations was increased when large deformation of the belt was occurred with low-stiff belt in clamping direction. Therefore, the pitch radius of the belt entering into pulley groove was depended on the deformation of the belt in pulley groove.

That is reason why reducing the stiffness of belt in clamping direction contributed to increase the shifting speed. This study showed that the shifting speed of CVT was improved when the stiffness of belt was reduced in clamping direction regardless of the belt type.

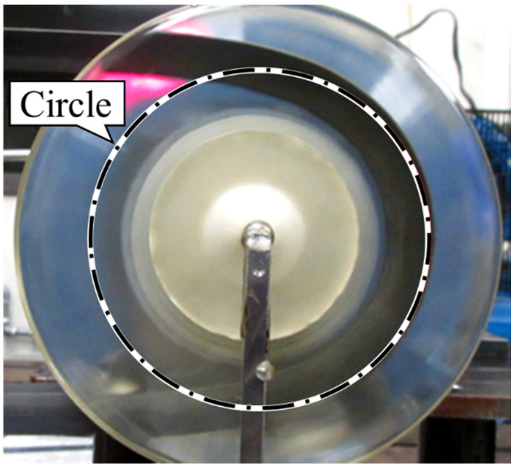


(a) In case of increasing of belt pitch radius

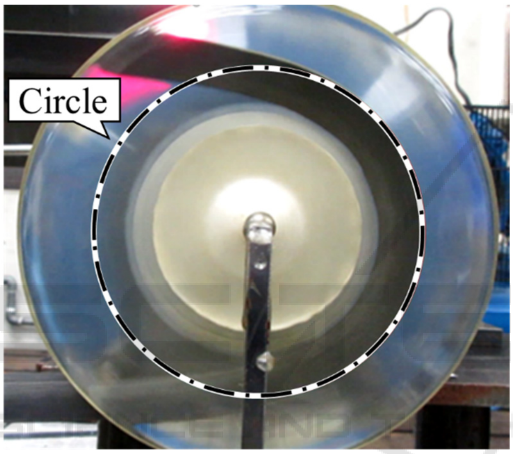


(b) In case of decreasing of belt pitch radius

Figure 12: Behaviours of push type belt in pulley groove.



(a) In case of increasing of belt pitch radius



(b) In case of decreasing of belt pitch radius

Figure 13: Behaviours of pull type belt in pulley groove.

5 FUTURE WORK

We are expecting these results should be applied to actual CVT with the metal V-belt and pulleys. To do this, we will evaluate appropriate dimensions such as the shape and material of belt.

6 CONCLUSIONS

This study investigated influence of the stiffness of V-belt in clamping direction on shifting speed of V-belt type CVT by observing the belt behaviour in pulley groove with semi-transparent pulleys. These conclusions were obtained as follow.

(1) At the case where the belt pitch radius was increased, the behaviour of belt elements in the pulley groove indicated that the remarkable radial slip between belt element and pulley was not occurred.

(2) The pitch radius of the belt entering into pulley groove was depended on the deformation of the belt in compression in clamping direction in pulley groove.

(3) The shifting speed of CVT was improved when the stiffness of belt was reduced in clamping direction regardless of the belt type.

REFERENCES

T. Fujii, K. Ookubo, Power Loss in CVT using Metal V-belt, *Journal of Society of Automotive Engineers of Japan, Vol.62, No.3, 2008,* p.58-65.

Yoshioka, Drivetrain, *Journal of Society of Automotive Engineers of Japan, Vol.66, No.8, 2012,* p.110-113.

T. Kanda, H. Totsuka, M. Oonuma, N. Shudo, T. Hirata, U. Ogata, Development of New CVT for Global Compact Car, *Honda R&D Technical Review, Vol. 26, No.26, April 2014*, p40-45.

T. Kawabe, Overview of Automotive Control in the Last Three Decades, *Journal of the Society of Instrument and Control Engineers, Vol.45, No.3, 2006,* p.161-166.

Y. Daisyou, Recent Trends and Future Perspectives on High Efficiency Automotive Powertrain Technologies, *Journal of Society of Automotive Engineers of Japan, Vol.69, No.9, 2015,* p.10-17.

S. Hikage, T. Hibi, K. Abo, Transmission Environment and CVT Technology, *Journal of Society of Automotive Engineers of Japan* Vol.58, No.1, 2004, p.63-68.

M. Yamanaka, Technologies and aspects for Smooth Cruising, *Journal of Society of Automotive Engineers of Japan*, Vol.61, No.12, 2007, p.4-8.

A. Aoyama, H. Sioiri, H. Akazawa, K. Suzuki, K. Kurokawa, O. Ogi, Future Trends and Outlook for Drive Train, Transmission Environment and CVT Technology, *Journal of Society of Automotive Engineers of Japan*, Vol.65, No.9, 2011, p.11-16.

Y. Asakura, Comments and Expectations for the Government Programs on Automated Driving Systems, *Journal of Society of Automotive Engineers of Japan, Vol.68, No.12, 2014*, p.6-11.

T. Uchimura, Automated Vehicle Implementation Effort in Europe and US, *Journal of Society of Automotive Engineers of Japan, Vol.69, No.12, 2015*, p.22-27.

S. Morishita, H. Watanabe, Approach to Automated Driving System in Japan, *Journal of Society of Automotive Engineers of Japan*, Vol.69, No.12, 2015, p.46-49.