Combined-Type Continuous Variable Transmission with Quadric Crank Chains and One-Way Clutches for Wind Power Generation

Toshihiro Yukawa1, Taisuke Takahashi1 and Shuzo Ohshima1

1Department of Mechanical Engineering, Faculty of Engineering, Iwate University, 4-3-5 Ueda, Morioka, Iwate, 020-8551, Japan

Abstract: Wind power generation using natural energy has been reviewed in terms of its efficiency in recent years. To increase the efficiency in the wind power generation system, we propose a new type of system where a continuously variable transmission (CVT) is mounted. Since the CVT can change the gear ratio continuously, it will be able to transfer energy from wind power to electric generator with high efficiency. The conventional CVTs have been classified as belt-type CVTs or toroidal CVTs. Each CVT is composed of several components to transmit the conduction force or torque generated by the input power. Since the conventional CVTs use friction force, the transfer efficiency of the wind power energy might be inferior due to slippage and pressure between the transmission components, if using it for wind power generation. Consequently, we propose a new type of CVT for the wind power generation system with high efficiency. The CVT we proposed means a combined-type transmission with quadrichain chains and one-way clutches.

Keywords: continuously variable transmission; quadric crank chain; one-way clutch; wind power generation; power generation efficiency; tribology

1. Introduction

Recently, wind power generation which is renewable and clean has been reviewed its efficiency performance. The most serious problem in wind power is that the air volume and its velocity is not constant although depending on the location, as it is well known. Since the starting torque of electric generator is comparatively high, and the starting torque of blade which mounted on windmill is also high, then the blade begins to rotate at last after overcoming the friction in the rotation axis. Thus, properties due to the friction around rotor or shaft, and the moment of inertia by the electric generator affect the efficiency of wind power. Some power management technology might be able to mitigate this problem when the efficiency of wind production is low.

In this paper, we explain a new type of a combined-type continuously variable transmission (CVT). The power transmission mechanism such as CVT has also been used in a vehicle, etc. The CVT mechanism between the input side and the output side is used to change not only the rotation power (force or torque) but also the rotation angle (or rotation velocity). The general view of a wind power generation system with CVT is shown in Fig. 1. The conduction mechanism between the input side (turbine, blade, etc.) and the output side (dynamo, etc.) includes gear transmission mechanism, traction mechanism, friction belts, pulleys, drive shafts and a torque converter. With respect to conventional CVTs, the belt types or toroidal types are basically composed of two transmission parts such as friction wheels. In the belt-type CVT, the pulley is driven by a belt placed between both sides of circle boards in the pulley. The gear ratio can be changed smoothly by controlling the diameter of the circle board of the pulley to contact with V-belt, and the CVT can transmit force/torque. In the toroidal CVT, two rollers rotate under the condition being pushed by a compression power. The power rollers are placed between the input and output disks, and are being pushed by strong compression power each other. The points of contact between both of input and output disks and the two power rollers are changed as the inclination corner of the power roller is changed along the rotation axis by another exterior force in order to change the speed ratio. Power between the disks and the roller is transmitted through the film of oil that forms. For the specification of CVT which mounted on commercial vehicles, the values of the gear ratios in the both situations between a high gear ratio and a low gear ratio can be set continuously in the range from about 0.4 to about 2.6.

In the conventional CVT, to prevent slippage between transmission components, the material often had been investigated from the point of view of the tribology field when selecting its material [1]. Since these CVTs use friction force occurring under high pressure at the contact points between the functional transmission mechanisms such as belt, pulley or rollers, and they cause huge power loss, their power transfer efficiency might be inferior. Furthermore, these conventional CVTs require precise structures and processing, they might make noise, and are not durable. Consequently, we propose a new structural CVT in this paper. The proposed CVT can compensate for the loss that originates in this high pressure. Finally, we develop this CVT in order to use in the power generation.

Many researches on various conventional CVTs have been done in the past. J. Ingvast et al. have proposed the new type of the transmission, an elastic conservative transmission [2]. The change in several ratios in PVT (passively variable transmission) depends passively on the load, in contrast to the general CVT. S. Miyata, et al. have designed the load control mechanism for the half-toroidal CVT [3], and they have discussed characteristics of the power split CVT. Also they have proposed the new analytical model. J. Kim et al. have proposed a new type of spherical-type CVT (S-CVT) by applying the conventional CVT mechanism [4]. Setlur et al. have realized a nonlinear control of CVT for the new hybrid vehicle power trains [5]. They have analyzed the energy efficiency of CVT-based mobile robots as the
application of the original CVT. Also they have proposed a simplified model for a vehicle with a spark ignition engine, and a CVT in a power split configuration. M. Pesgens et al. have proposed the control method of the CVT in an experimental vehicle [6]. Y. Itoh et al. have proposed a single ring CVT (MR-CVT) [7]. The MR-CVT features a self-adjustment mechanism that is the result of the design of the V-pulleys, guide rollers. Another researchers have been developed the new ratio controller for a metal push-belt CVT with a hydraulic belt clamping system.

The paper is organized as follows. Section 2 expresses a principle of quadric crank chain. Section 3 introduces the proposed CVT with quadric crank chains. Section 4 explains experiment results of the proposed CVT. Finally, section 5 gives conclusions and our future work.

2. Quadric Crank Chain

2.1 Fundamental principle of quadric crank chain

In this paper, we develop a combined-type CVT using quadric crank chains. This mechanism consists of closed loop-like links of the quadric crank chains. In the mechanism, there is a symmetrical arrangement of two crank-rocker mechanisms, which are composed of a closed loop consisting of four links [8-9]. Here we explain the principle of the proposed CVT for use in wind power generation. As a example of past analysis for the quadric crank chain, Gibson et al. have been derived the formation conditions of restraint in the four-bar linkage using the theory of Darboux [10].

The structure of a quadric crank chain is shown in Fig. 2. The lengths of links a, b, c and d are defined as \(a\), \(b\), \(c\) and \(d\). Each link is connected by rotation joints. In the quadric crank chain, there are four types of movements; i.e., double-crank (drag-link), crank-rocker (lever-crank), double rocker and parallelogram linkage. A double-crank mechanism and a parallelogram mechanism are continuously in motion, and a crank-rocker and a double-rocker mechanism’s motion are not continuous. Among these mechanisms, the crank-rocker mechanism is used for our CVT. The type of the movement in the crank-rocker mechanism depends on the relationship between the lengths of the links. Then, the link mechanism becomes a crank-rocker mechanism if the condition of the four link lengths is satisfactory. When the link \(a\), which is adjoined to rotation joints \(O\) and \(O'\), is fixed, the links of the quadric crank chain form a crank-rocker mechanism. In a precise sense, the condition that the movement of the crank-rocker mechanism is appropriate if and only if the sum of the lengths of the shortest link (crank b), and the link on the opposite side (rocker d) is smaller than the sum of the lengths of the other two links (connecting rod c and fixed link a).

That is, these inequalities:

\[b + c < a + d\]  \(1\)
\[a + b < c + d\]  \(2\)
\[b + d < a + c\]  \(3\)

must be satisfied to achieve the crank-rocker mechanism. It is possible to rotate the shortest link, b, which is the crank, completely around the rotation axis \(O'\). Link \(c\), the connecting rod, transmits the movement of the crank \(b\) to the rocker \(d\). The rocker \(d\) is shuttling corner moves by centering on rotation axis \(O\). A one-way clutch or a ratchet mechanism is used to transmit power from the movement of the rocker to other output rotation mechanism, which intermeshes alternately to the one-way crutch (or the ratchet) mechanism. In this crank-rocker mechanism, the rotation mechanism of the crank serves as the input function, and the rocker mechanism, as the output function. The speed ratio (the gear ratio) can be changed without stage by changing the length of the crank \(b\) and/or the connecting rod \(c\) continuously. Since the gear backlash of ratchet is generally larger than one of the one-way clutch, the one-way clutch is used. As
shown in Fig. 2, the power/torque which are generated by the back-and-forth angular movement of the rocker c is transferred to another outside rotation mechanism Q through a one-way clutch W. The one-way clutch has a structure which transmits force/torque in only one-direction. Then, the transferred power/torque changes to the output power in the CVT.

As for an application of CVT for wind power generation that has been proposed, the power is transmitted to the output side (the electric generator) for only one direction through the one-way clutch from the input side (blade of windmill or turbine blade). From this unique mechanism in which the power is not transmitted in the opposite direction, it is considered that the proposed CVT has advantage points in the situation even if the energy generated by wind is not constant. It is certain that the transmission efficiency of the proposed CVT will be greater since the performance of the mechanism does not depend upon the friction force under high pressure conditions.

2.2 Derivation of parameters and simulation of quadric crank chain

The derivation of each link length of quadric crank chain used in the CVT is explained. Let the line which connects the joint O to joint M be e, in the quadric crank chain mechanism. In the triangle of abe as shown in Fig. 3, the following formula can be obtained from the Pythagorean theorem.

\[ e = \sqrt{a^2 + b^2 - 2ab\cos\theta} \]  \hspace{1cm} (4)

\( \theta \) means the rotation angle of the input axis, and the link lengths of a and b are already set in design beforehand. Using Eq. (4), the angle \( \theta' \) as shown in Fig. 3 is given by

\[ \theta' = \cos^{-1} \frac{a^2 + e^2 - b^2}{2ae} \]  \hspace{1cm} (5)

Also, the link length of d is already set in design. When the length of connecting rod c (c') is being held without any control, there is no expansion and contraction of the connecting rod c (c'). Assume that the length of the connecting rod c is fixed at a constant length, at first. Using Eqs. (4) and (5), the angle \( \theta'' \) is given by

\[ \theta'' = \cos^{-1} \frac{d^2 + e^2 - c^2}{2de} \]  \hspace{1cm} (6)

If the length of connecting rod c is fixed, the rotation angle \( \phi \) at the output axis can be derived as follows:

i) In case of \( 2m \pi \leq \theta < 2m + \pi \) \((n=0,1,2, ...)

\[ \phi = \pi - \theta' - \theta'' \]  \hspace{1cm} (7)

ii) In case of \( 2m + \pi \leq \theta < 2m + 2\pi \) \((n=0,1,2, ...)

\[ \phi = \pi + \theta' + \theta'' \]  \hspace{1cm} (8)

When the input rotation speed is \( \theta = \omega = 2\pi \) [rad/s] and link lengths are \( a = 150 \) [mm], \( b = 49 \) [mm], \( c = 167 \) [mm] and \( d = 150 \) [mm], the angular velocity \( d\phi / dt \) in the output axis is shown in Fig. 4. The horizontal axis \( T \) stands for period of rotation at input axis. The absolute value of \( d\phi / dt \) can also be shown in Fig. 5. As described later, this absolute value is used to realize the proposed mechanism as a function of the CVT using two quadric crank chains with two one-way clutches which can transfer force/torque in only one direction.
3. CVT with Quadric Crank Chains

3.1 Principle of CVT with quadric crank chains

The outline of the CVT using two quadric crank chains is shown in Fig. 6. Two identical quadric crank chains, abcd and ab′cd′, are set symmetrically. The rotation axes O′ and O″, which are input sides, have to synchronize with each other, mechanically. Joints P and R swing when joints M and N rotate around the center of the rotation axes O′ and O″. With respect to the movement of the rockers d and d′, its speed differs on the initial and the return trips, and its acceleration is therefore not constant. This is called quick return mechanism of the quadric crank chains. Excepting a moment when the initial and return trips of the rocker switch, the acceleration of the rocker should be lost to transfer the power to the another outside rotation component Q smoothly. In other words, the speed of the initial and return trips should remain constant when the rotation speed of the input axis is constant, and both speeds should depend on each other. It is necessary to set the expansion and contraction movement of connecting rods c and c′, which are jointed between crank b and rocker d to provide this motion and achieve an equi-angular movement with constant velocity. The one-way clutch W can be installed in arbitrary points of the rocker d by an additional mechanism, e.g., i) the output rotation component Q in the case where the one-way clutch W is installed in the point P, ii) the output rotation component Q in the case where the one-way clutch W is installed in the point Q, which are shown in Fig. 6. As a result of the expansion and contraction, angle $\phi$ ($\phi'$) of rocker d (d′) becomes a triangular wave, and the derivative value, angular velocity $d\phi/dt$ ($d\phi'/dt$) of the link becomes a rectangular wave for time axis when the rotation speed $d\theta/dt$ ($d\theta'/dt$) of the input axis is constant. As a result, P and R repeat their motion with equal velocity in the direction of order, and the opposite direction every half cycle when the rotation speed of the input axis is constant. When the input axis rotates in one direction, output power can be transmitted only to one direction of the swing of the rocker using a quadric crank chain, so it is necessary to design the mechanism to conduct power continuously using at least two quadric crank chains. For instance, as one means of achieving continuous conduction of power, if the rotation phase of synchronizing links d and d′ is reversed by 180 degrees, then the swing phase of P is shifted to R by just a half-phase corresponding to a half-cycle. Thus, the rotations of links in input axis must be reversed through an idle gear, etc.

Next, we explain the function of a one-way clutch W (or a ratchet mechanism), which is used to make the power generated by the swing of rotation joint P (R) be conducted in only one direction. Two one-way clutches operating in the opposite directions are used to switch the normal and reverse directions of the rotation. When a one-way clutch moves along the opposite direction, the function of the one-way clutch becomes same as the bearing, no power is transmitted. That is, when the one-way clutch is idled with the output rotation mechanism Q, the one-way clutch goes over without any powers. Therefore, using two or more one-way clutches in two or more crank-rocker mechanisms, the parts Q can be rotated through the one-way clutch along only one direction at a constant speed.

By this method, whole system becomes a deceleration mechanism that can adjust the relationship between the angular velocity $d\theta/dt$ (and $d\theta'/dt$) of cranks b (and b′), and the angular velocity $d\phi/dt$ (and $d\phi'/dt$) of rockers d (and d′), by the expansion and contraction of cranks b (and b′) and/or the connecting rods c (and c′) with the prismatic joint mechanisms.

For another method of expansion and contraction for links such as cranks b, b′, and connecting rods c, c′, it is possible to change the reduction ratio by including a new link between O′M (O″N) and/or PM (RN). After all, the CVT mechanism has closed five links with a redundant degree of freedom. Another possible method is to put on cams in the
middle of cranks b, b’, and/or connecting rods c, c’. The cams can be driven by the input power. As a result, the swing of P and R becomes a uniformly angular velocity motion using the cams at half-cycle intervals.

3.2 Structure of the proposed CVT

The structure of the combined type CVT is explained. Fig. 7 shows the 3-D view of the CVT. Fig. 8 shows the front view (top view) of the CVT. As shown in Fig. 8, the cranks b (b’) are driven by the power generated at input axis through the spur gears S_A. A one-way clutch W is installed at the output axis Q. This time, the output axis Q corresponds to the rotation axis O. The one-way clutch W is intermeshed with a spur gear S_B which is installed around the output axis O. The spur gear S_B is also intermeshed with spur gears S_C. Links a and a’ do not exist in the CVT because the links in the quadric crank chains are fixed parts on a base.

As for the general mechanism of this CVT, there is a symmetrical arrangement of several chain mechanisms consisting of multiple n links. The most simple example is this link mechanism consisting of two crank-rocker mechanisms.

3.3 Derivation of parameters and simulation of CVT

Let the angular velocities of cranks b and b’ be constant. In Fig. 5, the sign of $\phi$ is changed at the moment of $T = 0.13$ and 0.70. Two swing angles of the levers were defined as $\phi$ and $\phi'$ in the former subsection. When $\phi$ or $\phi'$ becomes a positive value, the driving force is transmitted via the one-way clutch, otherwise, the force is not transmitted. The connecting rod c drives the force at the period from $T = 0.13$ to $T = 0.70$, and another connecting rod c’ drives the force...
at the period from $T = 0.00$ to $T = 0.13$, and from $T = 0.70$ to $T = 1.00$. Consequently, we can say that the length of the connecting rod $c$ should be controlled at the period from $T = 0.13$ to $T = 0.70$, and the length of the connecting rod $c'$ should be controlled at the period from $T = 0.00$ to $T = 0.13$, and from $T = 0.70$ to $T = 1.00$. As a result, the angular velocity $\phi$ of the lever $d$ becomes constant at the period from $T = 0.13$ to $T = 0.70$, and another angular velocity $\phi'$ of the lever $d'$ becomes constant at the period from $T = 0.00$ to $T = 0.13$, and from $T = 0.70$ to $T = 1.00$.

The maximum values of the lengths $c$ and $c'$ of the connecting rods in expansion and contraction are arbitrarily decided within the range of motion of the connecting rods $c$ and $c'$. The waveforms of $\phi$, $\phi'$ and its differential values can be selected according to arbitrarily gear ratios when designing beforehand.

Next, we determine the length of the connecting rod in order to realize the constant angular velocity of the output link. The length of the connecting rod $c$ ($c'$) can be derived from the next equation.

$$c = \sqrt{d^2 + c^2 - 2dc \cos \theta^e}$$

(9)

Upper Eq. (9) can be similarly obtained from the Pythagorean theorem using another triangle $cde$ in Fig. 3.

As the constrained situation for the lengths of the connecting rods $c$ and $c'$, we set the length of them as $c = 167$ [mm] in $T = 0.12$, and $c' = 167$ [mm] in $T = 0.69$, respectively. Then the range in the lengths $c$, ($c'$) of the connecting rods are set as 140-180 [mm]. The angle velocities of $\phi$ and $\phi'$ are set as 1.5 [rad/s] and -1.5 [rad/s], respectively. To realize the
constant angular velocity,
i) in case of $2m \leq \theta < 2m + \pi$ \((n=0,1,2,\ldots)\)
\[
\theta' = \pi - \theta' - \phi
\]  \hspace{1cm} (10)
and
ii) in case of $2m + \pi \leq \theta < 2m + 2\pi$ \((n=0,1,2,\ldots)\)
\[
\theta'' = \pi + \theta' - \phi
\]  \hspace{1cm} (11)
can be substituted to Eq. (9). In Eqs. (10) and (11), $\phi$ ($\phi'$) is already set, and $\theta$ ($\theta'$) can be derived by Eq. (5).

Fig. 10 shows the lengths $c$ and $c'$ of connecting rods which can be derived by the Eqs. (9), (10) and (11). This figure shows the length alteration of connecting rod $c$ at the period of $T = 0.14$ and $T = 0.69-1.00$, and the length alteration of connecting rod $c'$ at the period of $T = 0.12-0.71$. The reason for overlapping each control of $c$ and $c'$ between each brief period of $T = 0.12-0.14$ and $T = 0.69-0.71$ is to smooth switching of both links which transmit force/torque to the output component $Q$. The initial length value of crank $b$, connecting rod $c$ and angular velocity of the output component $Q$ were set to minimize the range of expansion and contraction of the connecting rod $c$.

As shown in Figs. 11 and 12, the velocities of expansion and contraction of the connecting rods $c$ and $c'$ were set to constant in the period when the one-way clutch mechanism $W$ is being idle. In these figures, it is understood that the lengths of both links $c$ and $c'$ are extended at constant speed in these periods. By changing the lengths of $c$ and $c'$, the angular velocity in the output axis $Q$ becomes constant at 1.5[rads]. As shown in Figs. 13 and 14, the minimum angular velocity $\phi'$ of lever d is -1.5[rads], and the maximum angular velocity $\phi$ of lever d' is 1.5[rads]. When the lever d rotates in the direction of positive angle $\phi$, and another lever d' rotates in the direction of negative angle $\phi'$, the delivered output force/torque is being transmitted to the output rotation component $Q$ via one-way clutch $W$. Since the absolute values of angular velocities in both links $c$ and $c'$ are equal to 1.5[rads] or -1.5[rads], the function as transmission of force/torque can be accomplished by the proposed CVT. Also, it was confirmed that the timing of expansion and contraction of the connecting rod indicated in Figs 11, 12, 13 and 14 was appropriate. After all, the reduction ratio was $4.19 = 2\pi/1.5$, when the rotation speed of the input shaft was set to $2\pi$ [rads].

### 4. Experiment

4.1 Contents of experiment

The entire view of the control system for the CVT is shown in Fig. 15. In the experiment, the link length and angular velocity in the CVT can be derived using measurement setup consisting of PC, A/D, D/A, counter and I/O boards (Fig. 16). The command to the angular velocity of each joint is sent to motors which are mounted on each link in the CVT through the motor driver. The rotary encoder was used for measurement of the CVT. The rotation angle and angular velocity in both input/output axes were measured through the counter board (Interface Corp.) mounted on the personal computer using rotary encoders (CB-2500LC, Line Seiki Co., Ltd., resolution 2500 [ppr]).

Experiment was performed to confirm whether the output component $Q$ in the CVT moves with a constant angular velocity or not. At first, the lengths of each link are set as $a = 150$ [mm], $b = 49$ [mm] and $d = 150$ [mm], and the gear ratio is set as 4.19. Although the angular velocity at the input axis was set to $2\pi$ [rads] in the simulation, an actual angular velocity at the input axis was set to 0.162[rads], judging from the characteristics of the motor used in the experiment. Then, the control of L-CVT was performed. Under the condition that the angular velocity of the input shaft was to 0.162 [rads], the theoretical value of the angular velocity in the output shaft was 0.0387[rads].

The response of the output axis was also measured in the condition when the reduction ratio equals 6.28. In this case,
a=150[mm], b=35[mm] and d=150[mm] were set as the length of each link, then the input output relationship in the proposed CVT was measured. The theoretical value of angular velocity of the lever at the output axis was 0.0258[rad/s], in the condition when the angular velocity of the input axis was 0.162[rad/s].

Finally, the lengths of links c and c' were fixed as 167[mm] in order to compare the experimental values with the theoretical values. Then, the angular velocity of the input and output shafts were measured, and the input output relationship was derived.

4.2 Experimental Results

In the developed CVT, the lengths of the links c and c’ were controlled in order to hold the rotation speed of the shaft in the output component Q to be constant under the constant rotation speed of the input shaft. Fig. 17 shows the actual rotational speed of the input driven by the motor through the spur gear $S_A$, and the speed is nearly constant. Fig. 18 shows the results of the angular velocity at the output axis, when the lengths of connecting rods c, and c’ are fixed with 167[mm].

Fig. 18 shows the experimental result (solid line), and the theoretical value (dotted line) shown in Fig. 5. When the lengths of connecting rods c and c’ are fixed, as shown in Fig. 18, it can be seen that measurement and theoretical values of the angular velocity at the output shaft coincide with each other. However, the angular velocity of the output becomes 0 [rad/s] at the moment when connecting rods c and c’ are switched, then the error between both values is increased. This is due to backlash of the spur gears $S_B$, $S_C$ and the one-way clutch mechanism W.

Fig. 19 shows the results the case where the controlled output becomes constant. For reference, the dashed line that means the result without control, was shown in Figs. 5 and 18, and is overlapped with the controlled value (solid line). The average of the angular velocity at the output axis was 0.0378 [rad/s]. One of the reduction ratio in the proposed CVT was set to 4.29. Error between theoretical values (4.29) and experimental value (4.19) was 2.4 [%]. The maximum value of the angular velocity was 0.0419 [rad/s], and the minimum value was 0.0344 [rad/s]. The variation in each curve

![Fig. 17 Angular velocity of input axis.](image1)

![Fig. 18 Responses of the angular velocity of rocker d. (theoretical and experimental values)](image2)

![Fig. 19 Responses of the angle of rocker d. (The lengths of connecting rod under control and non-control)](image3)

![Fig. 20 Output responses in the case when speed ratio is changed.](image4)
during two cycles was -9.9 [%] and 10.8 [%]. In particular, it is clear that the output value is disturbed at the moment when the driving by connecting rods c and c’ are switched each other. Of course, the constant angular velocity in the input side as shown in Fig. 17 did not influence the error in the rotation at the output axis. Fig. 20 shows the angular velocities of the output axis in case of two kinds of reduction ratio (4.19 and 6.28). The angular velocities are disturbed as well, regardless of the gear ratio when the links c and c’ are switched. If expansion and contraction of the connecting rod can be controlled holding the gear ratio of 6.28, an actual experimental value of the reduction ratio becomes 6.45. The error between the theoretical and experimental values were 2.7 [%]. The maximum value of the angular velocity was 0.0284 [rad/s], and the minimum value was 0.0219 [rad/s]. At that time, the variation in the angular velocity in two cycles was -15.1 to 10.0 [%]. By comparing time responses in experiment, the error in the gear ratio of 6.28 was larger than the state of 4.19.

5. Conclusions

We have proposed a CVT which is composed of quadric crank chains and one-way clutches. Since the proposed CVT is not based on friction conduction, it provides a mechanism that creates no noise and no slip, is durable, and can offer high transmission efficiency.

The appropriate geometrical condition of the links of the quadric crank chain was identified by simulation and experiment. Comparing the theoretical and measured results, it was confirmed that the CVT can be realized by controlling expansion and contraction of the length of links, and also it has arbitrarily transmission ratio.

In the next step, we will install the solid cam to the prototype model in order to change the gear ratio with expansion and contraction of links, mechanically. The CVT has a merit in which the rotation of the cam and crank at the input axis can be synchronized mechanically and automatically without electrical control. Furthermore, we are planning to evaluate the efficiency of power consumption of the CVT in the future.

Acknowledgements This work was supported by Grant-in-Aid for Scientific Research, KAKENHI (No. 23560149).

References


