Efficiency of a CVT Operated EVT Experimentally Evaluated against Half-Toroidal and Push-Belt CVTs

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Abstract—This article describes how an electrical variable transmission (EVT) can be used as alternative for mechanical continuously variable transmission (CVT) systems. An EVT is an electromagnetic power split device having two mechanical and two electrical ports. The speed ratio between both mechanical ports (rotors) can be varied in a continuously variable way, so that this machine can be used as electromagnetic alternative for the mechanical push-belt and half-toroidal CVT. Its operating principle is based on splitting the power into an electromagnetic direct path and an electrical path involving two inverters connected back-to-back. Its potential use as CVT is investigated by comparing experimental data against toroidal and belt CVT data from literature having comparable power ratings. To this end measurements are performed on a prototype 120 kW permanent magnet EVT.

Index Terms—Continuously variable transmission, Efficiency, Electrical variable transmission

I. INTRODUCTION

IN automotive applications the most well-known continuously variable transmissions (CVTs) are the metal belt drive CVT and the half-toroidal traction drive CVT [1]. Of these transmissions, the belt version has proven to increase driving comfort and decrease fuel consumption with 5 – 15% on average when compared to stepped automatic transmissions [2]. Therefore this transmission can be seen as the industry benchmark. Nevertheless, these mechanical systems can have some critical issues. Both CVT systems transmit torque based on mechanical contacts, inducing slip and friction. This requires lubrication and the need for traction fluid to transmit torque between metal parts [3], [4]. The gear ratio is restricted due to geometrical constraints of the design, requiring a clutch or torque converter to achieve standstill [5] and a reverse unit to change rotation direction. Furthermore, changing the gear ratio is often slow, and can cause additional wear [6].

Electromagnetic systems on the other hand could offer the advantage of reduced maintenance and higher efficiency

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Fig. 1: Schematic of a permanent magnet EVT used as CVT between combustion engine and wheels.

due to the absence of sliding contacts, pumping systems for lubrication and actuation, as well as the absence of a torque converter or reversing unit. Additionally, faster dynamics can be expected inherent to electrical drives. A diesel-electric transmission for instance consists of an electrical generator, a controlled rectifier, and one or multiple inverters and electrical motors. This principle is nowadays used in traction drives for ships, trains and heavy duty machinery [7]–[9]. Its main disadvantage is that the full output power needs to be converted by two electrical machines and two power electronic converters at least.

Other electromagnetic CVT systems try to overcome this drawback by combining a planetary gear set with two electrical machines [10], [11]. This system has the advantage that part of the input power is directly transferred to the output shaft, while only a part is converted in an electrical way. In other papers an alternative solution is proposed to improve the compactness and cost-effectiveness of the system by replacing the two electrical machines by one double rotor machine as in [12]–[14]. However, all previously mentioned solutions still require a mechanical gear box.

The double rotor electromagnetic CVT described in this paper also converts only a fraction of the input power through the inverters, while avoiding the use of a planetary gear set. The system is based on an electrical variable transmission (EVT), previously described in [15], and which can be seen as an electrical machine having two concentric rotors, as is

schematically shown in Fig. 1. The stator and inner rotor are hereby often equipped with a three-phase winding, each supplied by its own inverter. To supply the rotating rotors, slip rings are needed. The inverters are connected to a common dc-bus, supported by a dc-bus capacitor system. The outer rotor can be designed as a cage [16]–[18], PM rotor [19]–[23] or a combination of PMs with a dc-field winding [24], [25] as is the case in this paper. Calculations for an EVT used as power split device with storage and applied within a hybrid electric vehicle (HEV) are given and discussed in [26]–[29] where the focus is merely on the higher system level control. In this paper, the machine is considered without battery storage and the dc-bus is used to power additional equipment. Before introducing efficiency data of the EVT, there is the requirement of describing the operating principle of the machine used as CVT with focus on torque generation of different EVT parts and power flow within the machine and inverters. This is done in the first part of this paper. Next, the experimental EVT setup is introduced and efficiency and power flow measurements are given to support the theoretical conclusions. Finally the EVT performance is compared against results for belt and toroidal CVT data as given in the literature.

II. ELECTRICAL VARIABLE TRANSMISSION

A. Topology

A one pole pair cross section of the EVT, under consideration in this paper, is given in Fig. 2 where both rotors and stator can be seen. Both the stator and inner rotor windings are supplied by an inverter connected back-to-back to a common dc-bus. The outer rotor contains a combination of permanent magnets and a dc-field winding as done in [24], [25].

Fig. 2: Cross sectional view of the EVT, showing the stator (index s), outer rotor (index r2) and inner rotor (index r1).

The dc-field winding in combination with a flux bridge allows to change the stator flux linkage. The stator windings are used whenever there is torque difference between both shafts as will be described in section IV. This is particularly the case in case of acceleration from standstill, during which high stator torques are required. However, if the torque difference between both shafts is sufficiently low, as is the case in the direct drive

region, only limited stator torque is required. During such time intervals, often long, it is more efficient to link a small amount of the PM flux with the stator, hence reducing the iron losses in the stator. Also, since modulation of the stator magnetic field is performed with help of the dc-field winding, rather than by the stator currents, a smaller stator inverter can be used.

B. Principle of Operation

In this subsection the working principle of the machine is described based on simple power flow equations, and by neglecting the losses in the machine as mentioned in [15], [30], [31]. Despite the approximations made, these equations provide a very good understanding of the operation of the machine in different operating points. The equations are elaborated here for an EVT without battery storage. Also the effect of power take-off (PTO) on the power flow within the machine is shown.

Fig. 3: Power paths and sign conventions. As an illustration, the outer rotor speed equals half of the input speed.

In the case of an HEV, the inner rotor of the EVT is mostly connected to the ICE, while the outer rotor is connected to the final drive, as is the case in Fig. 3. In this figure, the sign conventions for a positive power flow are given. The electromagnetic torque T_{r2} on the outer rotor shaft is the sum of two contributions. First, there is the electromagnetic torque interaction from the stator onto the outer rotor, denoted by T_s in this paper. Next, there is the torque interaction from the inner onto the outer rotor, denoted by T_{r1} :

$$T_{r2} = (T_s + T_{r1}) \quad (1)$$

The product of torque and speed of the inner rotor shaft equals the mechanical input power $P_{m,r1} = T_{r1}\Omega_{r1}$ to the EVT. This is, if losses are neglected, converted to electrical power P_{pto} and to mechanical power $P_{m,r2} = T_{r2}\Omega_{r2}$.

$$T_{r1}\Omega_{r1} = P_{pto} + T_{r2}\Omega_{r2} \quad (2)$$

The ratio between input and output speed is hereby continuously variable. Depending on the speed ratio between both rotors and the required PTO, the power flow distribution within the machine itself will change. The mechanical power $P_{m,r1}$ is hereby split into two parts when entering the EVT. The part

$$P_{f,r1} = T_{r1}\Omega_{r2} \quad (3)$$

is, as shown in Fig. 3, directly transferred to the outer rotor shaft by means of the electromagnetic torque T_{r1} exerted by the inner rotor on the outer rotor rotating at angular speed Ω_{r2} . The remaining part

$$P_{el,r1} = T_{r1} (\Omega_{r1} - \Omega_{r2}) \quad (4)$$

is converted electrically by means of the inverter connect to the inner rotor. Combining (2) with (4) yields:

$$P_{el,r1} = P_{m,r2} \left(1 - \frac{\Omega_{r2}}{\Omega_{r1}}\right) + P_{pto} \left(1 - \frac{\Omega_{r2}}{\Omega_{r1}}\right) \quad (5)$$

The stator electrical power $P_{el,s}$ equals the inner rotor electrical power $P_{el,r1}$ from (5) minus the electrical PTO:

$$P_{el,s} = P_{m,r2} \left(1 - \frac{\Omega_{r2}}{\Omega_{r1}}\right) - P_{pto} \frac{\Omega_{r2}}{\Omega_{r1}} \quad (6)$$

The power split in (5) and (6) shows that only a fraction of the mechanical power is converted in an electrical way.

III. INVERTER RATING

As can be seen in (5) and (6), the electrical power flowing through the inverters is the superposition of two terms shown in Fig. 4a and Fig. 4b respectively. The first part is related to the mechanical power $P_{m,r2}$ of the outer rotor, while the second part is related to the power take-off P_{pto} .

As shown in Fig. 4a only part of the mechanical power converted by the EVT is converted in an electrical way, depending on the speed difference between both rotors. The remaining part of the power is converted in an electromagnetic way denoted by $P_{f,r1}$ in Fig. 3 due to electromagnetic torque between both rotors rotating at different speed. This way the rated inverter power can be a fraction of the rated mechanical power of the machine. Note that the mechanical power $P_{m,r2}$ at zero speed Ω_{r2} is zero as well in Fig. 4a so that the absolute value of the electrical power will reach a maximum in $\Omega_{r1} \in [0, \Omega_{r2}]$. This will be illustrated in subsection V-C where the experimentally measured power flows are shown. As for the PTO, both inverters need to be able to convert

the full PTO power as can be seen in Fig. 4b. At low speed, PTO is performed by the inverter connected to the inner rotor, while at higher speeds, more and more power is converted by the inverter connected to the stator. The power relations of Fig. 4 can be superimposed to know the resulting inverter power for stator and inner rotor. With the presence of PTO the inner rotor electrical power increases according to (5), while the stator electrical power decreases since both power terms in (6) partially cancel out. Note that this argumentation is only valid for $\Omega_{r1} \in [0, \Omega_{r2}]$. At negative ($\Omega_{r2} < 0$) and supersynchronous ($\Omega_{r2} > \Omega_{r1}$) speeds, circulating power terms are present, increasing the electrical power conversion by the inverters, even beyond $P_{m,r2}$ and P_{pto} .

IV. TORQUE RATING

In practice, the torque on both rotors of the EVT is controlled, rather than the power flow that is a result of torque and speed. At given speeds of both rotors, the outer rotor torque T_{r2} can be controlled resulting in a power $P_{m,r2}$ to the wheels. This outer rotor torque is the result of the electromagnetic torque contributions related to stator T_s and inner rotor T_{r1} as was given in (1).

A. Torque contributions

The inner rotor torque T_{r1} loads the ICE, and determines the mechanical input power to the EVT. This torque thus cannot be chosen independently, but is controlled by a dc-bus controller so that at any time the power balance:

$$P_{m,r1} = P_{m,r2} + P_{pto} + P_{loss} \quad (7)$$

or

$$T_{r1}\Omega_{r1} = T_{r2}\Omega_{r2} + P_{pto} + P_{loss} \quad (8)$$

is full-filled. P_{loss} represents the losses generated within the EVT and inverters, and is discussed later on in subsection V-B. The stator torque T_s is added to the inner rotor torque T_{r1} to result in the desired outer rotor torque T_{r2} , as was given in (1):

$$T_s = T_{r2} - T_{r1} \quad (9)$$

Fig. 4: Power converted by inverters connected to stator and inner rotor due to (a) mechanical power at output and (b) due to power take-off.

Fig. 5: Electromagnetic torque produced by stator and inner rotor windings due to (a) torque to outer rotor shaft and (b) due to power take-off.

With the inner rotor torque known from the dc-bus controller (8), the stator torque thus determines the resulting torque on the outer rotor. The torque relations are graphically given in Fig. 5. In Fig. 5a the torque on inner rotor and stator, resulting from a torque demand on the outer rotor, are given. In Fig. 5b the effect of PTO is shown. Both figures can be superimposed to know the resulting torque on stator and inner rotor if losses are ignored. Whenever the power balance of (8) is not full-filled, a net power will be withdrawn from or sent to the dc-bus capacitors. To this end, it is advised to add a small energy buffer.

B. Practical Implementation

The torque can be controlled by imposing appropriate currents through stator, inner and outer rotor windings. To control the torque on both rotors of the EVT, there are five independent current components to be controlled. Those are the stator q- and d-axis currents, the inner rotor q- and d-axis currents and the outer rotor dc-field current as can be seen in Fig. 2. Many combinations of currents thus yield the same torque, while the losses will be different for every set of currents. To this end, a torque controller is developed that calculates for every set of torque and speed values the optimal set of currents that minimizes the copper and iron losses in the machine [32]. It turns out that at low speed of the outer rotor, the stator current can optimally be controlled at constant load angle of about 120° with the PM-flux vector. The outer rotor dc-current is hereby set to increase linearly with the stator torque T_s . For the inner rotor finally, a constant load angle of 90° is optimal. At higher speeds, the stator flux is weakened by modifying the load angle and using the dc-field current.

V. EFFICIENCY MEASUREMENT AND LOSS SEPARATION

A. Demonstrator EVT

The relations, given in previous section, give the lossless working principle for a general EVT system. A schematic of the machine, under consideration in this paper, was given previously in Fig. 2. The corresponding experimental set-up in the lab is shown in Fig. 6, along with some electrical and geometrical machine parameters in Table I. The weight of this specific EVT prototype is about 115 kg. The overall length of this specific prototype machine with bearings, sliprings and casing included is 40 cm. For the measurements, 100Nm torque sensors with an accuracy class of 0.1% have been used.

Fig. 6: Experimental set-up

TABLE I: MACHINE PARAMETERS

	stator	outer rotor	inner rotor
rated mechanical power [kW]	-	120	75
rated current amplitude [A]	265	4.6 (dc)	150
max speed [rpm]	-	6000	6000
continuous torque [Nm]	245	382	137
maximum torque* [Nm]	410	652	242
number of pole pairs	4	4	4
outer radius [mm]	175	123.5	102
inner radius [mm]	124.5	103	57
active axial length [mm]	87	87	87
inverter rating [kW]	150	-	100
switching frequency [kHz]	12	-	12
DC-link voltage [V]	600	-	600

*Maximum torque based on 10s current limit of installed inverters.

For the experiments, induction machines were used to control the speed N_{r1} and N_{r2} of inner and outer rotor shaft. Both machines are shown in Fig. 6 as well. The outer rotor torque T_{r2} can be chosen independently, resulting in a desired mechanical power $P_{m,r2}$ to the load. The inner rotor torque T_{r1} on the other hand needs to be chosen as such that the input power from the ICE $P_{m,r1}$ equals the output mechanical power $P_{m,r2}$, the power take-off P_{pto} and the losses P_{loss} within inverters and EVT according to (8). This is done by a PI controller and by measuring the dc-current (power) to the common dc-bus of both inverters. A summary is given in the schematic of Fig. 7.

Fig. 7: Controller used for measurements.

B. Measured Overall Steady-State Efficiency

In this subsection, efficiency measurements on the demonstrator EVT are shown and discussed. Also, the different loss contributions are given, information that is valuable for further design optimizations. The results are shown in Fig. 8-10 for an input speed N_{r1} of 1500 rpm, 2000 rpm and 3000 rpm and for different outer rotor torque values. The torque values are limited by the torque sensors used to 100Nm on both shafts. The efficiencies are compared to a belt and toroidal mechanical CVT later on in subsection VI. As can be seen in the figures, the efficiency reaches a maximum if both rotors rotate at about the same speed. The reason is that at synchronous rotation and just before, the inverter loss, stator copper loss, the inner rotor iron loss and the friction losses of the bearings supporting the relative motion of the rotors reach a minimum as will be

Fig. 8: Measured shaft to shaft efficiency at input speed $N_{r1} = 1500$ rpm, $P_{pto} = 0$ W. Background color map represents simulation results.

Fig. 9: Measured shaft to shaft efficiency at input speed $N_{r1} = 2000$ rpm, $P_{pto} = 0$ W. Background color map represents simulation results.

Fig. 10: Measured shaft to shaft efficiency at input speed $N_{r1} = 3000$ rpm, $P_{pto} = 0$ W. Background color map represents simulation results.

shown in this subsection, where the different loss components are described into detail. Also shown in these figures are the predicted efficiencies from the loss models developed at the lab. The iron loss parameters from [33], [34] were hereby tuned based on no-load measurements. Also the bearing and

slip ring friction loss has been identified on the setup to be used in the loss models. High efficiencies up to 94% have been measured.

In order to fully understand the evolution of the efficiency, the different loss contributions need to be considered. The power losses generated within an EVT have a different nature than is common in mechanical CVT systems. A method to calculate and measure the different loss components within an EVT has been given in [35].

Fig. 11: Measured total and EVT machine losses at $T_{r2} = 50$ Nm. Theoretical loss decomposition is shown as well. Input speed $N_{r1} = 2000$ rpm, $P_{pto} = 0$ W.

Fig. 12: Measured total and EVT machine losses at $T_{r2} = 90$ Nm. Theoretical loss decomposition is shown as well. Input speed $N_{r1} = 3000$ rpm, $P_{pto} = 0$ W.

A detailed analysis of the main loss components according to this technique for an EVT used as CVT is shown in Fig. 11 and Fig. 12. These figures show the total measured power loss $P_{meas,total}$ in EVT plus inverters in red, and the measured power losses $P_{meas,EVT}$ within the EVT machine in blue for two given operating points of outer rotor torque T_{r2} and inner rotor speed N_{r1} . Also the theoretical loss decomposition is shown. The total measured power loss $P_{meas,total}$ is to be compared with the sum of all loss contributions. The measurement is the difference between mechanical power

measurement at inner rotor and outer rotor shaft, and is in good accordance with the theoretically expected loss. The measured EVT loss $P_{\text{meas,EVT}}$ is the measured loss without inverters. This was possible by measuring the inner rotor and stator electrical power as well using a power analyzer. As was already concluded from the efficiency measurements shown in Figs. 8-10, the power losses reach a minimum near synchronous rotation of both rotors. To understand the evolution of the losses in Fig. 11 and Fig. 12, and thus efficiency in Figs. 8-10, the most important loss components are briefly discussed here:

- The inverter losses are the sum of the losses generated in both the inverters connected to stator and inner rotor, and mainly depend on the inverter current and thus electromagnetic torque produced by stator and inner rotor. From Fig. 5, it can be seen that from zero speed towards synchronous rotation, the torque T_s generated by the stator decreases, while the torque T_{r1} generated by the inner rotor increases. This results in slightly decreasing inverter losses since the inverter connect to the stator has the higher losses. At supersynchronous operation, both torque components increase in absolute value (circulating power region) so that the total inverter losses increase when increasing the outer rotor speed.
- The same is true for the copper losses, that are a quadratic function of the torque. Indeed, the stator copper losses $P_{\text{cu,s}}$ decrease towards synchronisation of both rotors to increase again in the supersynchronous speed region. The inner rotor copper losses $P_{\text{cu,r1}}$ increase quadratically with outer rotor speed, also in accordance with Fig. 5. Note that, when increasing the outer rotor torque, copper losses will become more and more dominant.
- The iron losses P_{fe} are the dominant loss term in the machine itself in the considered operating points. The stator iron loss increases with outer rotor speed N_{r2} while the inner rotor iron loss is related to the speed difference $N_{r2} - N_{r1}$ between both rotors as is illustrated in Fig. 11 and Fig. 12
- Also the mechanical friction losses in the bearings and slip rings are shown. The loss related to the bearing, supporting the inner rotor, remains constant at constant inner rotor speed, as are the inner rotor slip ring friction losses. The loss of the bearings, providing the relative motion of the rotors, decreases towards synchronization of both rotors, while the outer rotor bearing loss increases.

All these considerations result in the net friction loss shown in the figures.

C. Measured Power Flow

Finally, in order to support the theoretical derivation in Section III, the corresponding electrical and mechanical power flow in the machine is given in Fig. 13.

The figures show, as theoretically expected in Fig. 4, that only part of the power is transmitted in an electrical way if the outer rotor speed N_{r2} is lower than the inner rotor speed N_{r1} . The evolution of the electrical power as function of speed is a quadratic function. Indeed, the mechanical power

Fig. 13: Measured and predicted power flow at $T_{r2} = 90$ Nm and given input speed N_{r1} .

increases linearly, and the electrical power is a linear function of the mechanical power as shown in Fig. 4. Note that the difference between the input mechanical power $P_{m,r1}$ and output mechanical power $P_{m,r2}$ equals the sum of all loss components in the machine and inverters. The difference between the inner rotor electrical power $P_{el,r1}$, and stator electrical power $P_{el,s}$ equals the inverter loss. The losses have been explained into detail in the previous subsection.

VI. EVT COMPARED TO MECHANICAL EQUIVALENT

In order to situate the EVT performance with respect to other transmission systems, the machine is compared against measured mechanical CVT data in literature. In this paper a comparison is made by comparing measured efficiency data from a half toroidal [36], [37] and a push-belt CVT [38] with the measured EVT data from this paper having comparable system ratings and system volume. The half toroidal CVTs in [36] and [37] have a comparable maximum output torque as the EVT in the order of 350 Nm and 430 Nm respectively. For the belt CVT in [38], torque ratings up to 200 Nm are reported only .

A. Steady-State efficiency

The measurements in [36]–[38] have some operating points in common to those used to obtain the steady-state efficiency measurements in this paper. Both data are shown in Fig. 14 and Fig. 15 for the half-toroidal and push-belt CVT respectively together with measurement data from the EVT. The efficiencies are plotted as function of the input torque T_{r1} for different gear ratios $r_g = \frac{N_{r2}}{N_{r1}}$. Note that these were the shaft-to-shaft

efficiencies for which both machine and inverter losses are taken into account.

Fig. 14: Measured part load steady-state efficiency comparison between EVT and half-toroidal CVT from [37] at input speed $N_{r1} = 1500$ rpm and [36] at input speed $N_{r1} = 2000$ rpm. Different gear ratios r_g are considered. Note that for the half-toroidal CVT no hydraulic pump losses were taken into account.

As can be seen in Fig. 14, the toroidal and EVT efficiencies are very similar in the operating points reported in literature. However, it has to be noted that for the toroidal CVT measurements only the variator losses are taken into account. This does not include losses for applying a clamping force on the variator and/or changing the tilting angle of the power rollers. Also, the power loss in an additional planetary gear set - required to have the same functionality as an EVT - is not accounted for.

Fig. 15: Measured part load steady-state efficiency comparison between EVT at input speed $N_{r1} = 3000$ rpm and push-belt CVT from [38] at input speed $N_{r1} = 2865$ rpm.

The pump losses are taken into account comparing the push-belt efficiencies with the corresponding EVT efficiencies in Fig. 15, as are the variator torque and slip losses and the final reduction gear loss. As can be seen in this figure, the EVT has higher steady-state efficiencies in the operating points shown. The variation in the push-belt efficiency measurement is due to the slip control. The lower limit represents the standard slip

control used in a commercial belt CVT, while for the upper efficiency limit the slip control has been further optimised.

B. Gear Ratio

As stated before, the gear ratio r_g of the mechanical CVT systems is geometrically limited. This way, standstill of the outer rotor is not possible at rotating inner rotor, nor is reversing of the outer rotor with respect to the inner rotor. This consequently results in the need for a torque converter or clutch with reversing unit or a planetary gear set. For the EVT in this paper, the gear ratio lower limit is negative, so that both standstill and reversing are inherently possible. However note that negative gear ratios ($r_g < 0$) and oversynchronous rotations ($r_g > 1$) will result in circulating power.

Fig. 16: Measured and predicted power flow at $T_{r2} = -30$ Nm and input speed $N_{r1} = 1000$ rpm.

Power flow in oversynchronous operation was shown in Fig. 13a where the input speed $N_{r1} = 2000$ rpm, while the output speed was increased until $N_{r2} = 3000$ rpm. It was noted in the figure that the converted electrical power increases quadratically with the output speed. A similar figure is shown here in Fig. 16 for reversing operation. The converted electrical power increases again quadratically and beyond the converted mechanical power. Consequently, the oversynchronous and reversing regions are limited in power, particularly by the choice of the inverters, as described into detail in section III and the torque ratings of both stator and inner rotor, as was discussed in section IV. In practice, reversing or standstill will only use low powers.

C. Overload Protection and Overload Capability

Finally, the EVT has the advantage that no mechanical connection exists between input and output shaft. This means that an inherent overload protection between both shafts exists eliminating the need for a torque fuse. Also vibrations between both shafts are inherently damped. The other way around, the EVT can also produce an overload torque which is thermally limited in time, as can also be seen in Table I. This feature, which can be used for short (but hard) accelerations, is an advantage compared to mechanical transmissions for which the rated torque is equal to the maximum torque and is limited by the maximum allowable clamping force [6].

VII. CONCLUSIONS

In this paper, it has been shown that an EVT can be used as continuously variable transmission with electrical power take-off (PTO). The input power is split into an electromagnetic and electrical path. Without PTO, the fraction of the total power converted electrically, is ideally a linear function of the outer rotor speed, decreasing towards synchronisation of both rotors. Measurements show that the EVT has comparable efficiencies as the toroidal CVT. Because however the hydraulic pump losses of the latter are not considered, all in all the EVT will have a better efficiency than the toroidal CVT. Compared to the belt CVT, the EVT shows an efficiency increase of more than 10% over the entire measurement region. The EVT has the additional advantage that no additional clutch or torque converter is required. Moreover it has inherent overload protection, fast dynamics and high overload capability. Therefore, the EVT seems a viable alternative to consider for mechanical automotive CVTs.

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