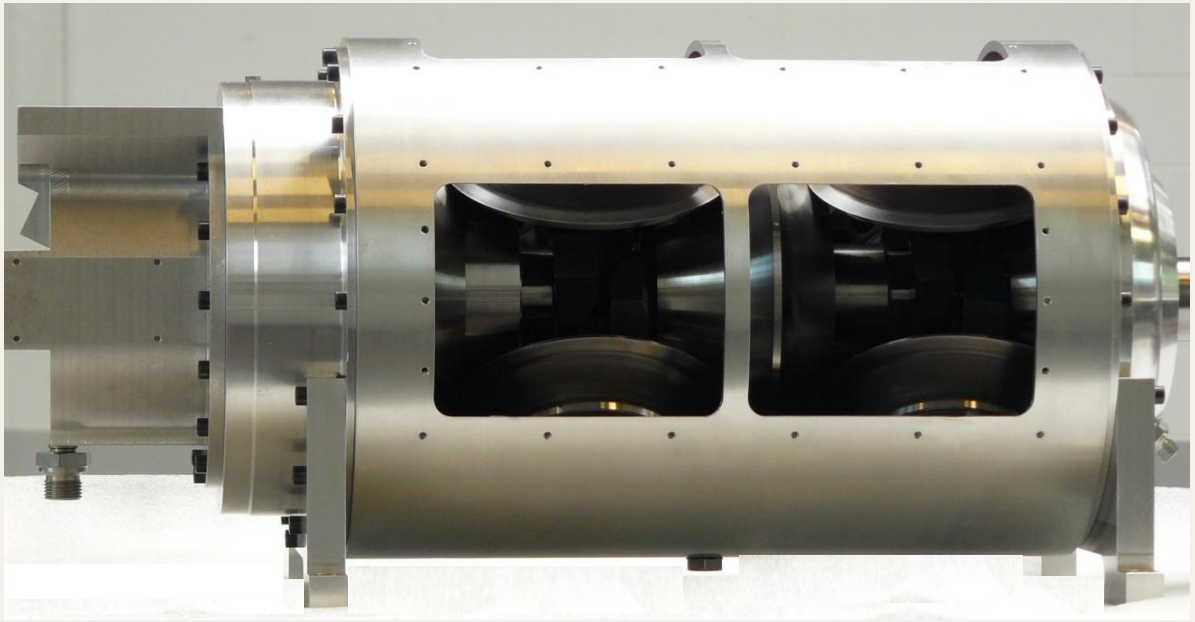
THE **REVERSIBLE VARIABLE** TRANSMISSION

23% LESS FUEL & EMISSIONS(*)
EXCITING DYNAMICS
COMPACT DESIGN WITHOUT CLUTCH

for cars, city buses, coaches, trucks, off-highway machinery, all terrain vehicles. Suitable for vehicles running on any kind of energy source: gasoline, diesel, hydrogen,… including hybrids

(*) compared to a 6 speed Automatic Transmission in an exurban drive cycle



FROST.COM 2015 VISIONARY INNOVATION LEADERSHIP AWARD

"MAZARO OFFERS A RADICALLY NEW WAY OF TRANSMITTING ENGINE POWER WITH ITS RVT TECHNOLOGY" - F&S

The RVT has been honoured with Frost & Sullivan's 2015 VISIONARY INNOVATIVE LEADERSHIP AWARD in the automotive transmission industry.

Main criteria:

- Focus on unmet needs
- Blue Ocean strategy
- Technological sophistication
- Thorough knowledge of current mega trends
- Dedication to the vision of developing a futuristic transmission technology
- Company culture pursuing excellence.

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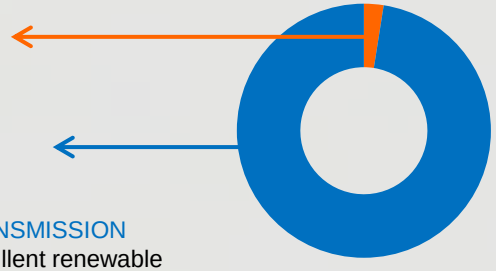
TODAY'S MAIN AUTOMOTIVE CHALLENGE

EXPECTED WORLD PASSENGER CAR SALES IN 2035*
- INTERNATIONAL ENERGY AGENCY -

PURE ELECTRIC VEHICLES

ENGINE DRIVEN VEHICLES, INCLUDING HYBRIDS



ALL CONTAINING AN ENGINE + TRANSMISSION

Today, most run on fossil fuels but excellent renewable fuel alternatives are on their way.

* Source: International Energy Agency - World passenger vehicle sales in the New Policies Scenario; www.slideshare.net/internationalenergyagency/biofuels-andtransport-futures-iea-views-to-2015-2030-2050

→ DRASTIC ENGINE POWERED DRIVELINE IMPROVEMENT CAN REVOLUTIONISE FUEL, CO_2 AND COST SAVINGS

Current transmissions all have limitations: they contain inefficient parts, their frequent gear shifting causes extra energy loss and they are mostly complex, heavy and voluminous. The strategy of adding more gears for a wider ratio spread has reached its limits because of growing complexity and cost and because too much shifting is inefficient in itself.

Current continuous variable transmissions have the advantage of operating without gears but their ratio spread is still limited, they too contain inefficient parts and internal drill-slip brings efficiency further down.

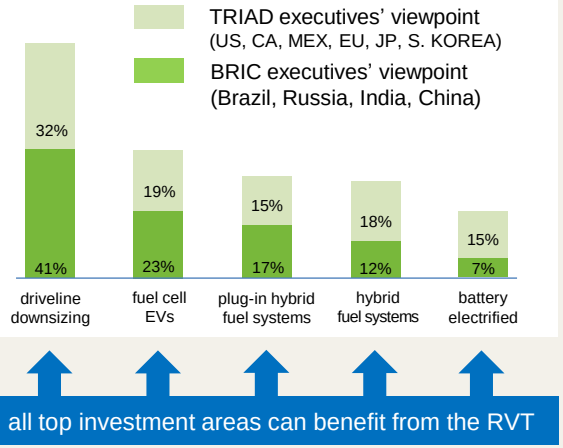
THE RVT FOR DRASTIC ENGINE POWERED DRIVELINE IMPROVEMENT

To make the RVT best in class, its design started from a blank page to avoid all limitations of current systems and create a totallyfresh way to transmit power. Besides its high internal efficiency,

THE RVT IS THE ONLY SYSTEM IN THE WORLD THAT CAN KEEP THE ENGINE AT ITS LOWEST CON-SUMPTION CURVE AT ALL TIMES

To achieve this, the RVT is conceived as an advanced continuous transmission system (CVT) without the downsides of current CVTs.

Automotive executives' top powertrain technology investment areas in 2015 up to 2020 (Source: KPMG's Global Automotive Executive Survey 2015 p. 17):



all top investment areas can benefit from the RVT

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TRANSMISSION ISSUES CAUSING EFFICIENCY LOSSES	TYPICAL FOR	RVT SOLUTIONS FOR HIGHER EFFICIENCY
gear shifting creates losses & reduces torque	MT - AT – AMT - DCT	fluent continuum of power transmission without the need for gear shifting
slipping components which burn power	MT - AT - AMT - DCT CVT - HST	no slipping components
need for a clutch or torque converter which slips (dry clutches wear) especially during continuous slow driving (tractors, construction vehicles, lift trucks…)	MT - AT - AMT - DCT CVT	ability to creep endlessly without wear thanks to absence of slipping components. RVT can also make hybrids more efficient
limited ratio spread so that the engine cannot always run on its most fuel efficient point for the requested output power	MT - AT - AMT - DCT CVT - HST	extremely wide ratio spread, corresponding to a theoretical 13 -4 shift transmission. The engine can always operate at its most fuel efficient point for the requested output power
pumps running continuously for compensation of leakage by hydraulic piston rings	AT - AMT – DCT - CVT	no piston rings
internal drill slip limiting efficiency and torque capacity	CVT	mathematical pure rolling without drill slip making the RVT scalable to many applications
ISSUES REDUCING COMFORT		**SOLUTIONS FOR MORE COMFORT**
delay between pushing the throttle and drive-off wasting time and fuel to rev up	MT - AT - AMT - DCT CVT	immediate drive-off for vivid dynamics powerful drive-away with engine at idle
manoeuvring requires various actions and is not always precise (lift trucks, tractors…)	MT - AT - AMT	joy-stick precise manoeuvrability
noise due to gears, oil pump, air bubbles in oil, fast running engine	MT - AT - AMT - DCT CVT	oil without air bubbles, smooth traction surfaces instead of gears, quieter engine
ISSUES ADDING EXTRA COST		**SOLUTIONS FOR LOWER COST**
complex, voluminous and heavy	AT - AMT - DCT – HST	very simple, few componensts, compact and light weight
large engine to compensate for improper transmission ratio or low efficiency	MT - AT - AMT - DCT CVT - HST	high efficiency + always exactly right ratio allows for engine downsizing
adding extra gears (up to 9 or even 10) to extend the required ratio spread	AT - AMT - DCT	extremely wide ratio spread is typical of the RVT's basic design principle

MT: Manual Transmission
AT: Automatic Transmission
AMT: Automated Manual Transmission
DCT: Double Clutch Transmission
CVT: Continuous Variable Transmission
HST: HydroStatic Transmission

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THE RVT COMPARED TO CVTs

CVTs transmit power continuously without gear shifting which saves fuel but current systems have limitations which the RVT has solved:

NO DRILL-SLIP

The rolling surfaces of all CVTs suffer drill-slip causing power losses. But the RVT's rolling surfaces are specially designed to avoid this effect; they simply roll over each other as do cones with coinciding tips. This mathematically pure rolling minimizes power losses and oil heating.

NO CLUTCH, NO SYNCHRO'S

An RVT changes driving direction from forward to reverse and back in one fluent continuum without clutches or synchronizers. Driving away happens without slipping components. This again, adds to higher efficiency and cost cutting.

60% LONGER RATIOS

In a passenger car, the RVT's speed ratio extends 60% further than an 8 speed AT or than other CVTs. This enables the most efficient engine use.

IDEAL FOR KERS

Combining RVT & flywheel can recover <u>all</u> kinetic energy thanks to its zero speed ratio, without losing energy in a slipping clutch or torque converter. Current CVTs perform less well here, as they cannot go to zero speed ratio and need a torque converter.

RVT STRENGTHS IN DETAIL:

23% LESS FUEL & EMISSIONS

COMPARED TO A 6 SPEED AT IN AN EXURBAN DRIVING CYCLE

→ **17-20%** gained by the utmost efficient use of the engine. The RVT controls the engine speed so that the engine runs at its best efficiency curve in all driving conditions;

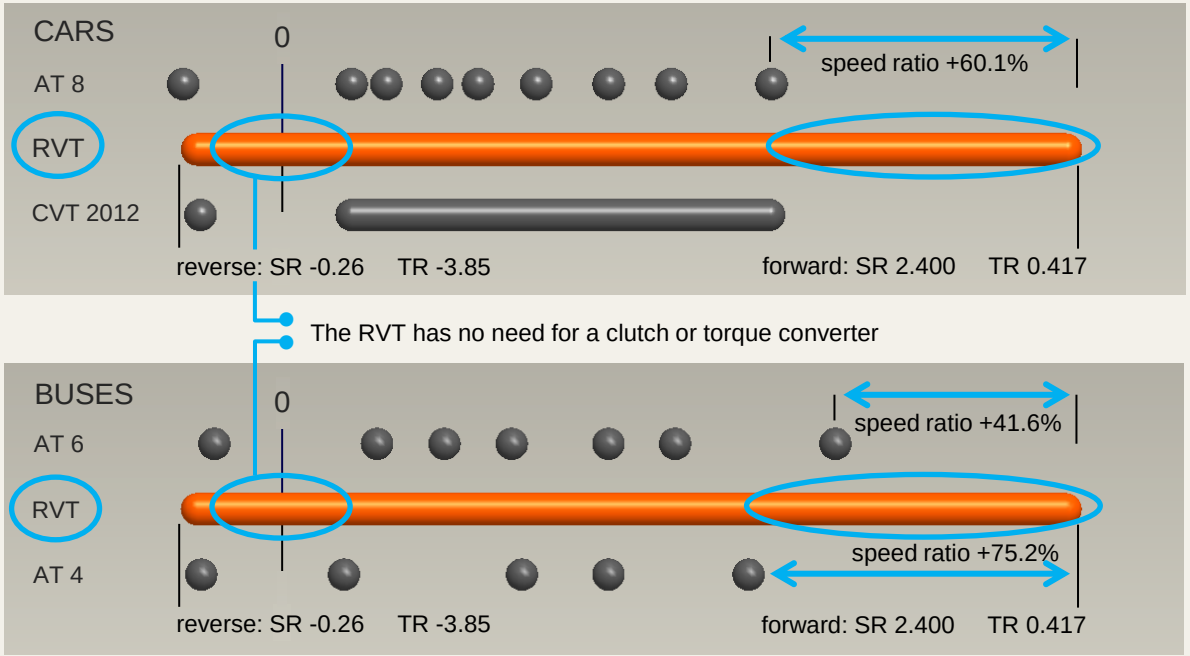
→ **1-3%** from better transmission efficiency;

→ **1-3%** from the absence of slipping clutches, torque converter, synchronizers or any other slipping component.

ALLOWS ENGINE ALWAYS TO RUN ON ITS LOWEST CONSUMPTION CURVE

- EXCEPTIONALLY LONG SPEED RATIO FROM -0,26 OVER 0 to +2,4
- MINIMUM SPEED RATIO 0 (ABSOLUTE STANDSTILL WHILE SUPPLYING OUTPUT TORQUE WITH ROTATING INPUT)

The highest ratios of the current transmissions are still not high enough for optimal engine efficiency. The RVT however, has such a long top ratio that it always keeps the engine at its ideal speed for lowest fuel consumption for the requested output power. *(fig. 1)*



(Fig. 1): comparison of speed ratios from various transmission systems in cars and buses

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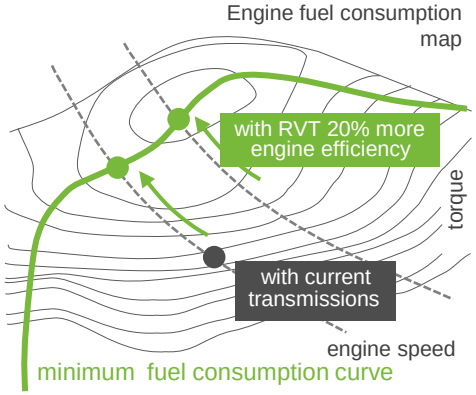


RVT: 1st transmission able to keep the engine at all times on its most fuel efficient point for the requested output power

VIVID DYNAMICS: THROTTLE RESPONSE IN 58 MS

The RVT's immediate response to the throttle's commands is able to give the driver a sensation of rocket dynamics.

All current transmissions need more time to change ratio, even a DCT. The RVT makes immediate reactions an exhilarating reality.

Maximum drive away acceleration is instantly available at the very start of pushing the throttle when the engine is still at idle speed.

All other cars need time to bring the engine to speed before reaching enough driving force. The RVT launches within 58 ms.

SMOOTH CONTINUOUS CHANGE OF RATIO AND DIRECTION, WITH-OUT EFFICIENCY OR TORQUE DIP

All current transmissions besides CVT only dispose of a limited number of distinct gear ratios to select from. To improve fuel economy there is a current tendency towards more gears.

But this principle has practical and financial objections and even then, while changing the ratio, all current transmissions have a low efficiency while changing the ratio.

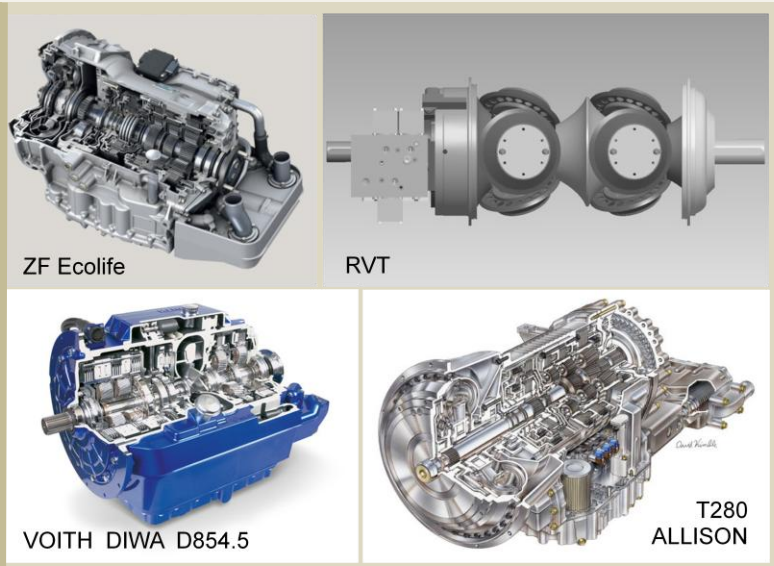
The RVT is the transmission with a continuous high efficiency even while changing ratio.

LEAN & COMPACT TO REDUCE COSTS

The RVT contains no slipping parts which are troublemakers: slipping clutches, synchronizers and torque converters cause serious efficiency losses and piston rings need leakage for cooling, so the oil pump has to run constantly. Without piston rings, the pump can be switched off at constant ratio (on average, the pump needs only 25 Watt). The RVT contains only few sensors and solenoids as they are sensitive and prone to malfunctioning.

Eliminating these parts reduce cost, weight and size. The RVT is considerably lighter than standard automatic systems of the same torque capacity. Designed for a projected input torque of 560 Nm, its

Parts which the RVT doesn't need



Note the RVT's simplicity compared to other transmissions

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max outer diameter is only 280 mm as the transmission can do without the mentioned parts.
The complete RVT (incl. housing, excl. hydraulics and electronics) contains only 37 different make parts, far less than all other transmissions. *(fig. 2)*

ALLOWS FOR A SMALLER ENGINE FOR THE SAME PERFORMANCE

The RVT's higher dynamics and efficiency allows for a smaller engine for the same performance.
The vehicle can accelerate while keeping the engine continuously at its max power point. This has an additional positive effect on the reduction of fuel consumption, emissions and production cost.

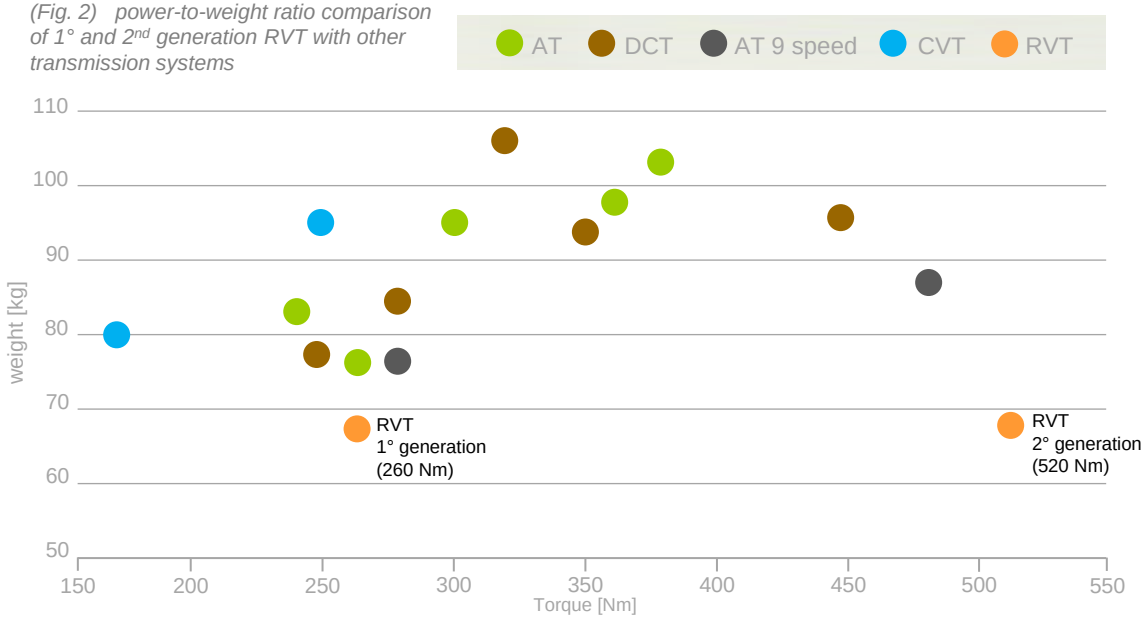
UNLIMITED CREEPING WITHOUT HEAT GENERATION

The RVT can also stay at standstill or drive very slowly - forward or reverse - without any slipping component. Very practical when manœuvring up- or downhill, or on slippery surfaces.

This creeper speed ability is especially useful for off-highway vehicles in construction or agriculture and for all-terrain cars.

Creeping can be done for an unlimited time without overheating anything and without a cooler.

(Fig. 2) power-to-weight ratio comparison of 1° and 2nd generation RVT with other transmission systems



POWERFUL DRIVE-AWAY FROM SPEED RATIO ZERO

When driving away from standstill, the RVT's speed ratio gradually increases starting from 0. This means high output torque as of idle engine speed.

In systems with a slipping clutch however, the engine needs to be revved up first in order to deliver sufficient engine torque.

LOW NOISE & VIBRATION

Only a small oil flow goes through the driving components, so that the oil for the hydraulics remains free of air bubbles. This reduces the pump's noise and vibrations considerably.

The smooth rolling of the inner parts and absence of gears all help to lower the noise to a minimum. Also the engine produces less noise as the RVT makes it run at lower speed.

LOW MAINTENANCE

The RVT's low maintenance is ensured by its robust design, absence of wearing components and batteries. Oil temperature remains low which reduces the need for oil changes.

ECU NEEDS NO ADAPTING

The Engine Control Unit needs no adapting to the RVT; it's the RVT that adapts to the engine. Naturally, the advantages of the RVT allow for further optimization of the engine's ECU.

HOW IT WORKS

Six planet wheels which tilt, rotate round their own axis and around the main shaft, transmit power by traction without drill-slip.
The ratio and the driving sense are controlled by changing the axial position of the main shaft: the position of the main shaft defines the tilting angles of the planet wheels.

A forced zero output speed is obtained by keeping the planet wheels horizontal. The highest speed ratio of the shown model is 2.4 (corresponding torque ratio: 0.417), but different ratio ranges in forward and reverse can be designed according to the requirements of the application.

RVT & KERS

Extra saving is achieved with a mechanical Kinetic Energy Recovery System consisting of an RVT and a flywheel. This system recovers nearly all kinetic energy created by a vehicle's deceleration thanks to the RVT's 0 speed ratio, without losing energy in a slipping clutch as does a CVT.

The rotating flywheel transmits the recovered energy to the wheels while accelerating, which means extra savings on fuel, emissions and engine noise.

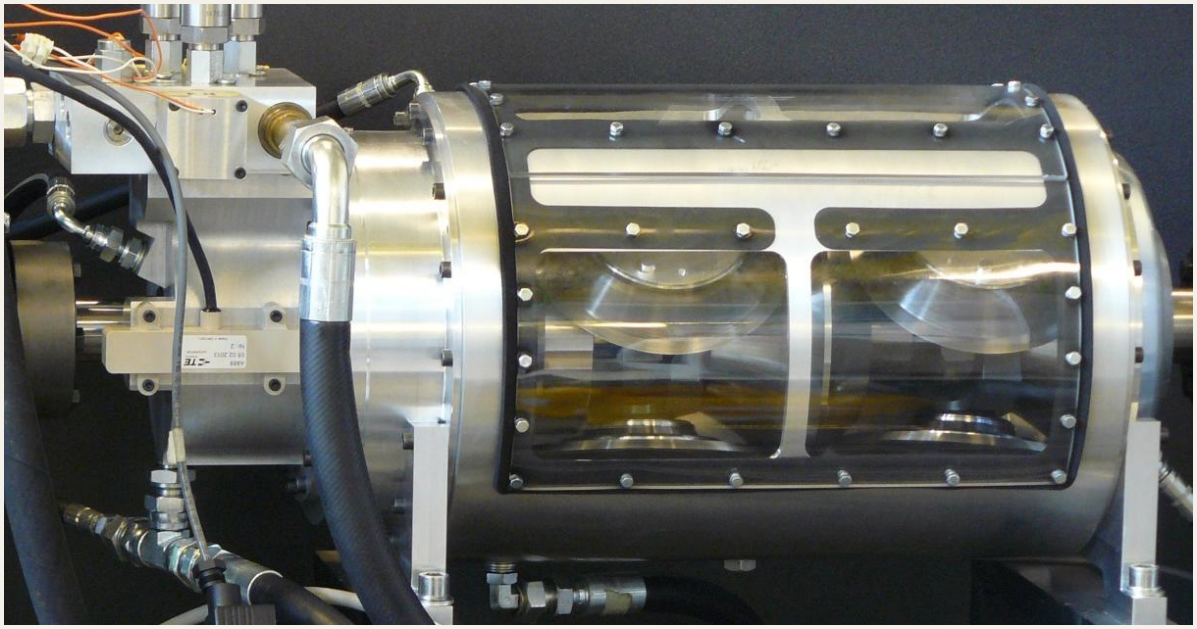
The extremely high efficiency of the traction without drill-slip keeps overall efficiency very high even at low speed ratios.

THE RVT IS NO TOROIDAL CVT

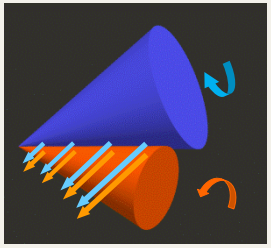
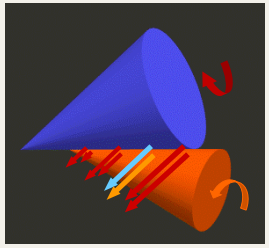
The rolling surfaces of a toroidal system roll over each other as do cones of which the tips do not coincide. When the surface speed of both cones is equal at one contact point, slip occurs at all other points.

The rolling surfaces of an RVT system roll over each other as do cones of which the tips coincide. When the surface speed of both cones is equal at one point, the surface speeds are equal at *every* point on the contact line.

Mathematically pure rolling is obtained, avoiding energy consuming drill-slip.



INTERNAL DESIGN PRINCIPLE

RVT: NO SLIP	OTHER TRACTION DRIVE CVTs: SLIP
	
mathematically pure rolling: → **no** drill-slip	tips do not coincide. no pure rolling: → **drill-slip**

SUITABLE FOR

- PASSENGER CARS

RVT's in- and outgoing shafts are inline so in RWD & 4WDs no adaptation of the car's internal architecture is needed. The RVT is also fit for FWDs if a gear pair is added between engine and RVT.

- LIGHT - MEDIUM - HEAVY DUTY TRUCKS

For these vehicles, fuel cost and emission savings plus extra driving comfort during long trips and traffic jams are the RVT's main benefits.

- CITY BUSES - COACHES

As city buses frequently stop and depart, the benefit they get from the RVT is particularly high.

- A city bus+RVT: 21% fuel savings.
- A city bus+RVT+RVT/KERS: 56% fuel savings.

- OFF-HIGHWAY MACHINERY

Besides fuel and emission savings, it is the transmission's ability of unlimited creeping with speed control and efficient direction changes that makes the RVT so outstanding for these vehicles.

- ATV - SNOWMOBILES

ATVs sporting an RVT can expect exhilarating dynamics and low maintenance for less fuel & CO_2.

- AUXILIARIES–INDUSTRIAL APPLICATIONS

Auxiliaries needing a variable or reversible power transfer like compressors, generators, cooling fans, bus airco's and pumps can be driven over a small RVT to drive these equipments continuously at their optimal speed or to keep them at standstill.

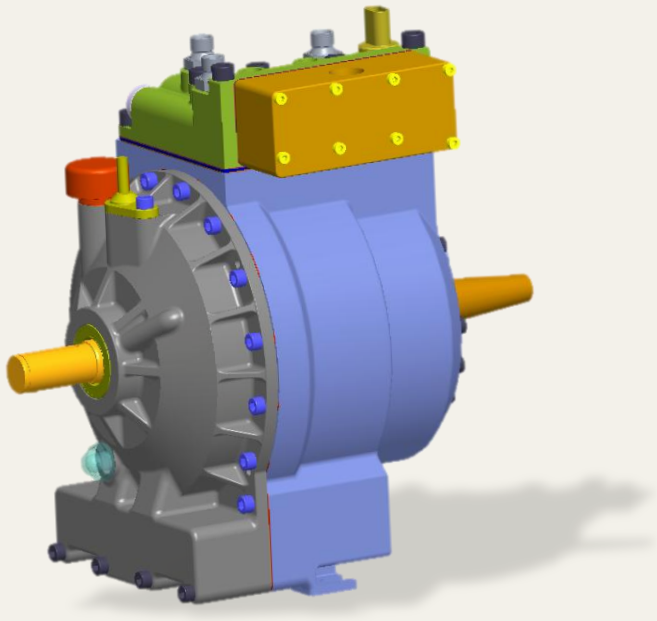
SINGLE STAGE SV210 **VARIATOR**

ELIMINATING THE NEED FOR A FREQUENCY CONVERTER

A small device based on the same technology as the RVT functions as an energy-saving continuous speed variator, keeping auxiliaries and industrial applications on their most efficient speed independently from the engine speed as e.g. engine roots compressors, compressors to brake or for airco, cooling fans, refrigerators,…

Combining the SV210 Variator with a fixed-speed generator is a much cheaper way to obtain a stable frequency than a directly driven variable-speed generator with a frequency converter, two expensive components.

- The SV can vary output speeds (different from zero) with a spread of up to 3,5;
- Transmits output torque for start-up and driving, even without hydraulic pressure;
- Input shaft can support radial loads from belt drive
- High mechanical efficiency: 96,9 %.



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CURRENT DESIGNS

The products mentioned below have been designed on request.
These can be up- or downscaled to fit the specifications of other types of vehicles and machinery.

RVT 125 **For 150 hp car** 1st generation	RVT 220 **For off-highway** 2nd generation	RVT 230 **ATV & snowmobile** 2nd generation	SV 210 variator **For auxiliaries** 2nd generation
Max speed ratio in forward			
+2,400	+2,124	+1,212	+0,655
Max speed ratio in reverse			Min speed ratio
-0,23	-0,415	-0,129	+0,364
Max output torque (Nm)			
507	3 500	556	50
Max input speed (RPM)			
4 500	2 300	3 900	> 9 000
Max output speed (RPM)			
7 300	2 600	4 720	3 000
Max power (kW)			
110	81	74	16
Length (mm)			
600	793	438	201
Diameter (mm)			Height x width (mm)
280	460	298	284 x 200
Efficiency averaged over driving cycle			
89,8%	92,1%	92,2%	96,9%

Filip De Mazière is the designer of the RVT. He has been designing transmissions and clutches for over 25 years for manufacturers of high-end sports cars, passenger cars, off-highway vehicles and material handling equipment (Liebherr, CNH, Knorr Bremse, Kalmar, McLaren, Ferrari…). Filip holds a Master Science degree in Mechanical Engineering (University of Ghent, Belgium) and has several patents for automatic transmissions, DCTs and off-highway powershifts some of which are in production since the nineties.

In 2009 he co-founded **Mazaro**, an engineering company concentrating on making the RVT production-ready for specific applications, consisting of the design and calculation of mechanical aspects, physical models and controls software. Mazaro is also engaged in research and testing to evaluate components, transmissions and subsystems.

filip.demaziere@mazaro.eu

SPECIFICATIONS
RVT 220
& shorter version RVT 240

DESIGNED FOR

off-highway vehicles for construction, agriculture, material handling equipment, harbour & airport ground support equipment; buses, garbage vans, …

FEATURES

- Very high overall transmission efficiency using the engine at its optimal regime at all times (for RVT 220) or nearly so (RVT 240), significantly saving on fuel and emissions
- Offering variable ratios down to zero and in reverse
- No torque or efficiency dip during ratio variation
- Powerful acceleration and unlimited creeper speed without risk of overheating
- Fast and accurate control of output speed or of the speed ratio
- Unnoticeable delay on request for ratio change
- No or very low maintenance expected
- Robust & light weight with very few components
- Silent operation
- Input and output shaft are in line.

TECHNICAL SPECIFICATIONS
(current status of development)

Model name	RVT 220	*shorter version: RVT 240*
Design application	off-highway, buses, vans, trucks, …	
Transmission length	858 mm	*737 mm*
Transmission outer diameter	460 mm	*432 mm; locally 470 mm*
Transmission weight excl hydraulic pump	250 kg	*223 kg*
Highest speed ratio forward (torque ratio)	2.124 (TR 0.471)	*1.519 (TR 0.658)*
Highest speed ratio reverse (torque ratio)	0.415 (TR 2.410)	*0.435 (TR 2.299)*
Lowest speed ratio	0.000	
Max input torque	516 Nm	
Max input speed	2 200 RPM (+ safety margin)	
Max output torque	3 800 Nm	
Max output speed	2 604 RPM	
Reference power	81 kW	
Overall max efficiency incl hydraulic pump	94.2%	*93.7%*
Transmission slip by torque transfer	< 0.25% (included in efficiency)	
Reaction time on ratio change request	58 ms	
Typical inaccuracy on dynamic ratio request	0.3 % = 3 RPM output error on 1000 RPM input	
Typical inaccuracy on static ratio request	0.01 to 0.001 %	

The RVT lay-outs described here can be redesigned to meet other application requirements

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SPECIFICATIONS
RVT 230

DESIGNED FOR

Compact, high power vehicles: ATVs, snowmobiles.

FEATURES

- Very high overall transmission efficiency using the engine at its optimal regime at all times, significantly saving on fuel and emissions
- Offering variable ratios down to zero and in reverse
- No torque or efficiency dip during ratio variation
- Powerful acceleration and unlimited creeper speed without risk of overheating
- Fast and accurate control of output speed or of the speed ratio
- Unnoticeable delay on request for ratio change
- No or very low maintenance expected
- Robust & light weight with very few components
- Silent operation
- Input and output shaft are in line.

TECHNICAL SPECIFICATIONS
(current status of development)

Model name	RVT 230
Design application	leisure vehicles up to 101 hp
Transmission length	438 mm
Transmission outer diameter	270 mm, locally 298 mm
Transmission weight excl hydraulic pump	54.6 kg
Highest speed ratio forward	1.212 (torque ratio 0.825)
Highest speed ratio reverse	0.129 (torque ratio 7.752)
Lowest speed ratio	0.0
Max input torque	186 Nm
Max input speed	3 900 RPM
Max output torque	556 Nm
Max output speed	4 720 RPM
Max power	74 kW
Overall efficiency	92.2% incl. hydraulics
Transmission slip by torque transfer	< 0.25% (included in efficiency)
Reaction time on ratio change request	58 ms
Typical inaccuracy on dynamic ratio request	0.3 % = 3 RPM output error on 1000 RPM input
Typical inaccuracy on static ratio request	0.0 to 0.1 %

The RVT lay-out described here can be redesigned to meet other application requirements

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SPECIFICATIONS SV 210 VARIATOR

DESIGNED FOR

auxiliaries and industrial applications benefiting from a variable or reversible power transfer as e.g. engine roots compressors, compressors for braking, generators, cooling fans, vehicle airco's, pumps…

FEATURES

- Very high overall efficiency significantly saving on fuel and emissions
- Very short transmission offering variable ratios (all output speeds in the same driving direction, no neutral)
- No torque or efficiency dip during ratio variation
- Transmits output torque for start up and driving even without hydraulic pressure
- Input shaft can support radial loads from belt drive
- Fast and accurate control of output speed or of the speed ratio
- Unnoticeable delay on request for ratio change
- Eliminates the need for a frequency converter
- Robust & light weight with very few components
- No or very low maintenance expected
- Silent operation
- Input and output shaft are in line

TECHNICAL SPECIFICATIONS (current status of development)

Eliminates the need for a frequency converter

Model name	SV210 – single stage variator 210
Design application	driving auxiliaries at variable defined speeds, independent from input speed
Transmission length	204 mm
Transmission width	200 mm
Transmission configuration height	289 mm (incl. hydraulic controls)
Transmission weight incl hydraulic pump	18 kg (partly compensated by downsizing compressor)
Highest speed ratio	0.952 (torque ratio 1.05)
Lowest speed ratio	0.501 (torque ratio 1.996)
Ratio spread	1.9
Max input torque	50 Nm
Max input speed	6000 RPM (11000 RPM on request)
Max output torque	50 Nm
Max output speed	3000 RPM (5500 RPM on request)
Max power	15.7 kW (28.8 kW on request)
Max output torque w/o hydraulic power	7 Nm
Overall efficiency excl. / incl. hydraulic pump	96.9 % excl.; 95.9 % incl.
Max input speed variation for constant output speed	1400 to 2000 RPM/s while supplying 50 Nm output
Reaction time on ratio change request	58 ms
Typical inaccuracy on dynamic ratio request	0.15 % = 1.5 RPM output error on 1000 RPM input
Typical inaccuracy on static ratio request	0.0 to 0.05 %

The variator lay-out described here can be redesigned to meet other application requirements

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