Continuously variable transmission (CVT)

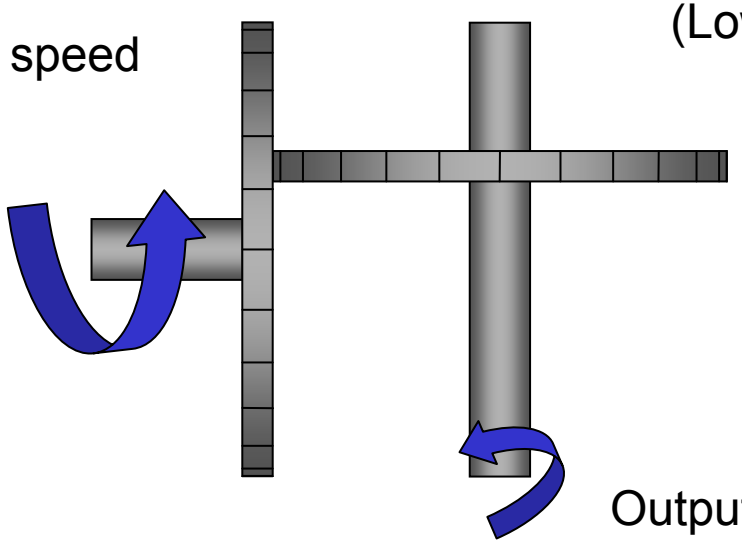
CVT

- CVT allows for the operation at the lowest possible speed and highest possible load, partially avoiding the low efficiency region of the engine map.
- A continuously variable transmission (CVT) transfers power through a range of speed/torque ratios from engine input to output, continuously without interruption
- Contrast with either manual or conventional automatic transmissions that use discrete ratios and normally disengage when changing ratio
- The CVT category includes infinitely variable transmissions (IVT) that give a zero output speed within the operating range

Simple Friction Drive

Low Output Speed
(Low gear selected)

Constant input speed



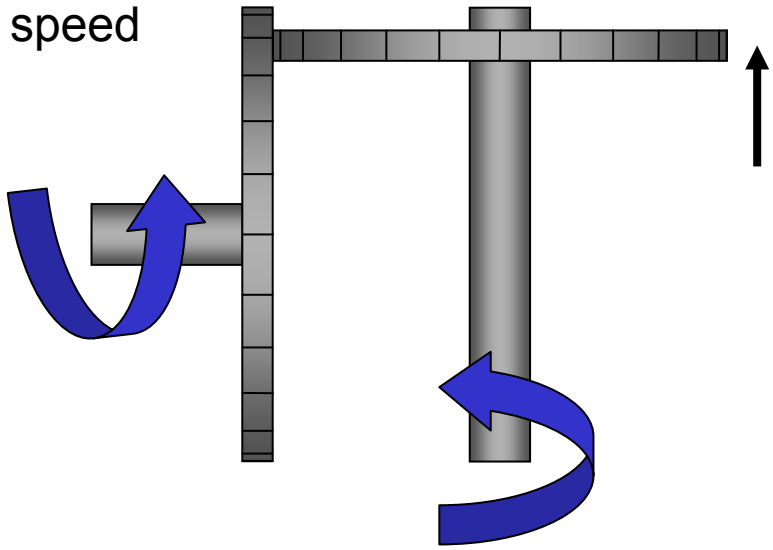
Engine driven
input shaft drives
disc with friction
surface

Output shaft
connects to wheels

Friction Drive: High Speed

High output speed
(top gear, high ratio)

Constant input speed

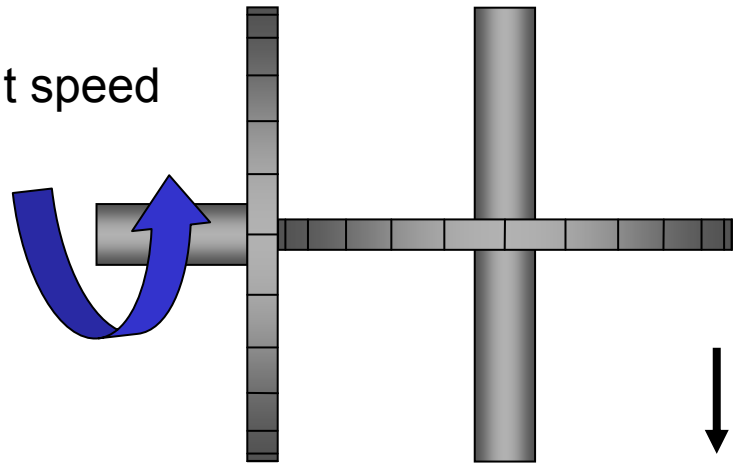


Movement between ratios takes place without steps and gives a continuous change of ratio

Friction Drive: Zero Output

Geared Neutral with input rotating gives IVT

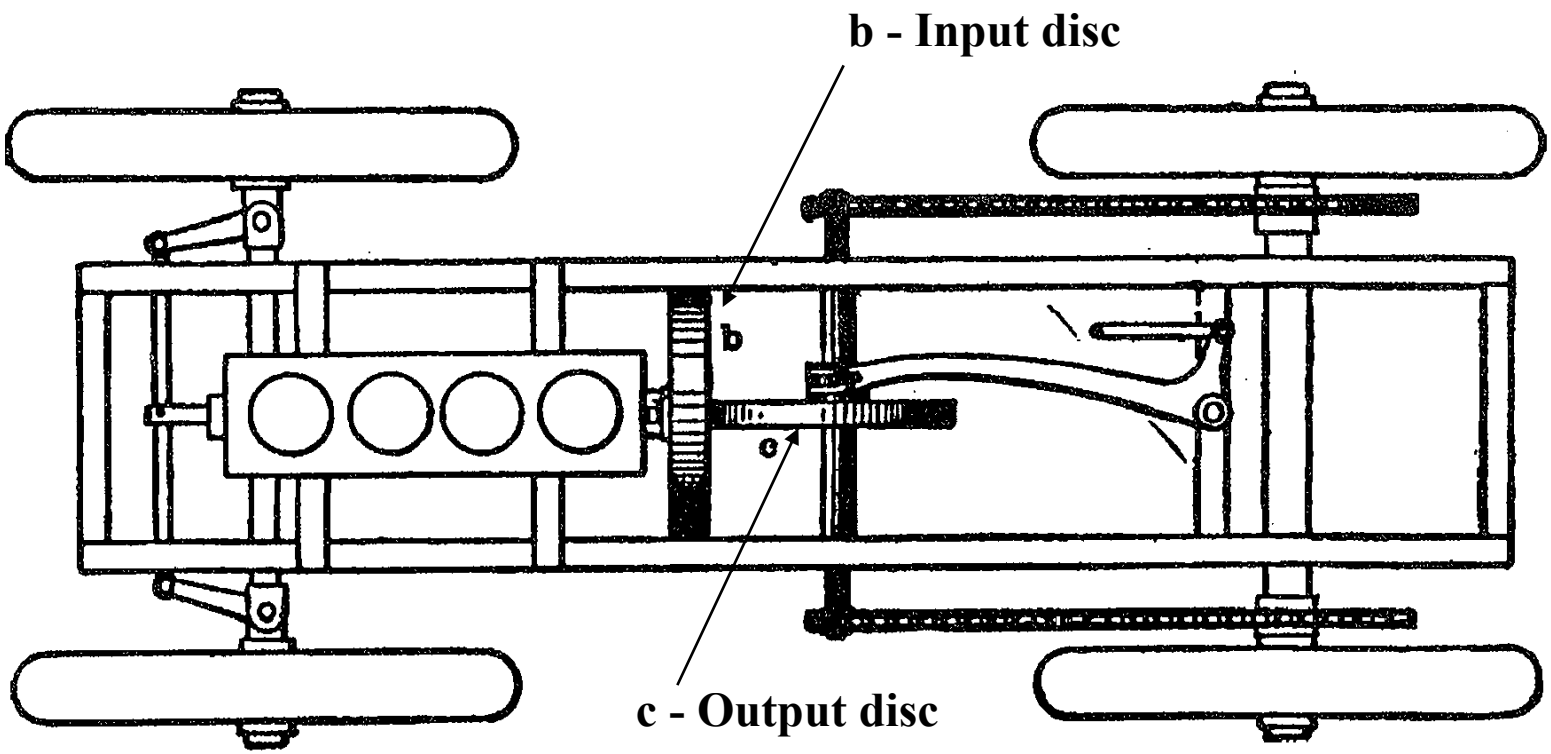
Constant input speed



Zero output speed when disc moved to line up with centre of rotation of input shaft

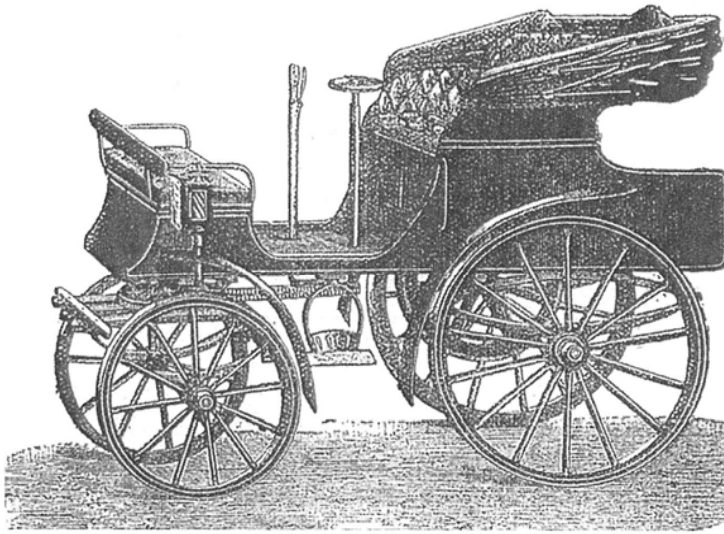
Reverse output speed possible if output disc moved below input centre line

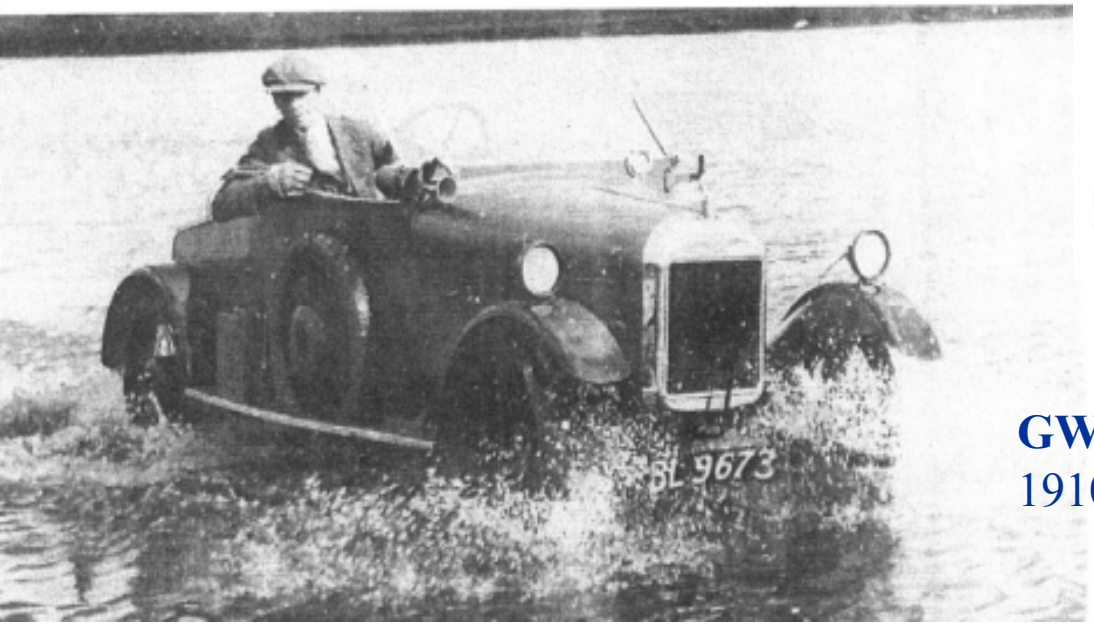
Vehicle Layout



Disc Friction Drive CVT

FIRST CAR: Tenting,
France 1891





GWK of Maidenhead
1910-1931, two seat cyclecars

CVT Categories & Targets

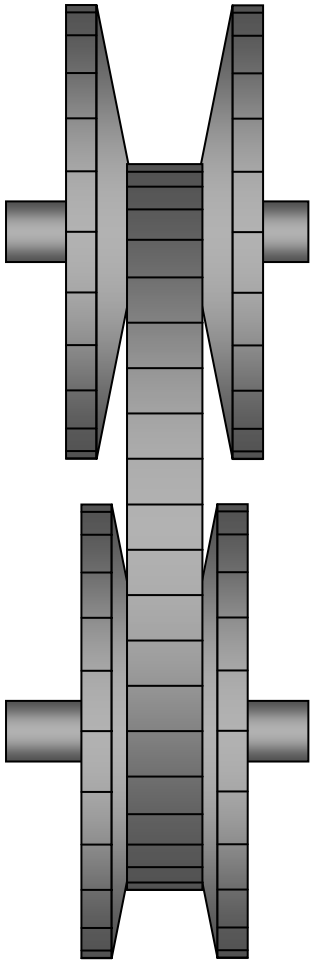
- Successful CVT will resolve the compromises in reliability, durability, efficiency, and controllability with low cost
- Implementation of commercially produced CVTs transmit drive through friction
- Variable pulleys with flexible belt or chain
  - sliding friction
- Traction drives with rotating surfaces
  - rolling contact, shear friction

Variable Pulley

- Variable pulley systems are based on the common v-belt pulley fixed ratio layout with power transfer through a flexible element connecting between two pairs of pulley sheaves.
- Flexible element may be a belt or chain
- Sheave movement usually controlled by hydraulic or electrical means

Variable Pulley Drive

Constant input speed

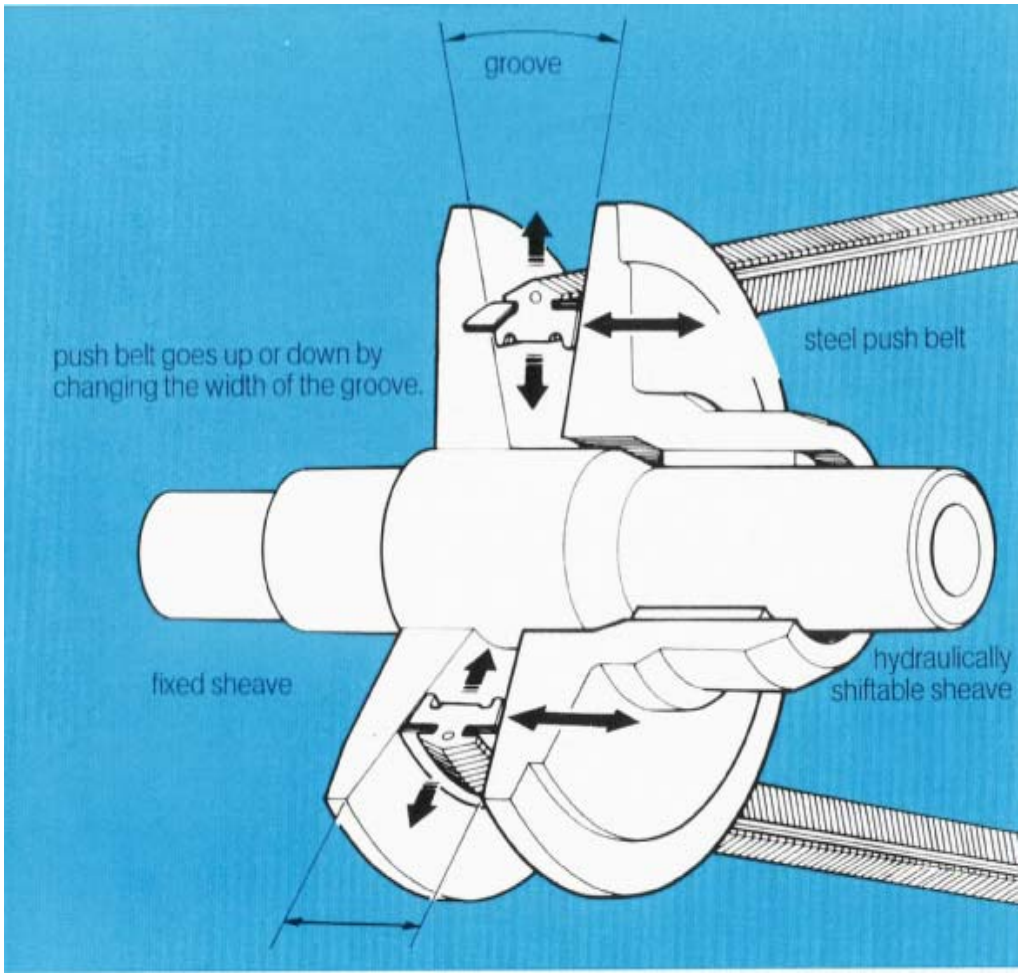


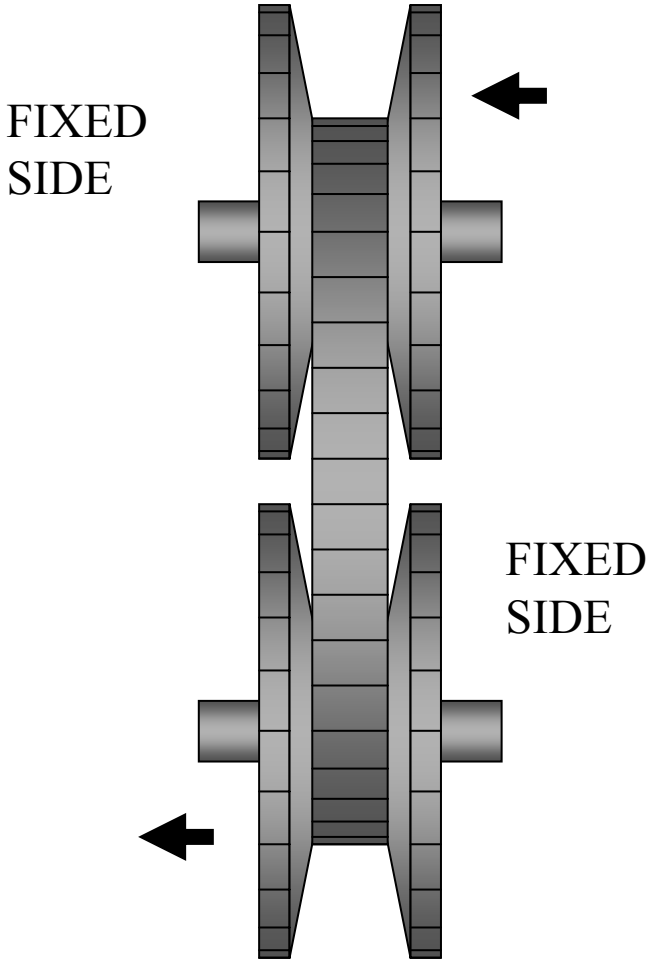
Small radius of flexible belt

Low Ratio

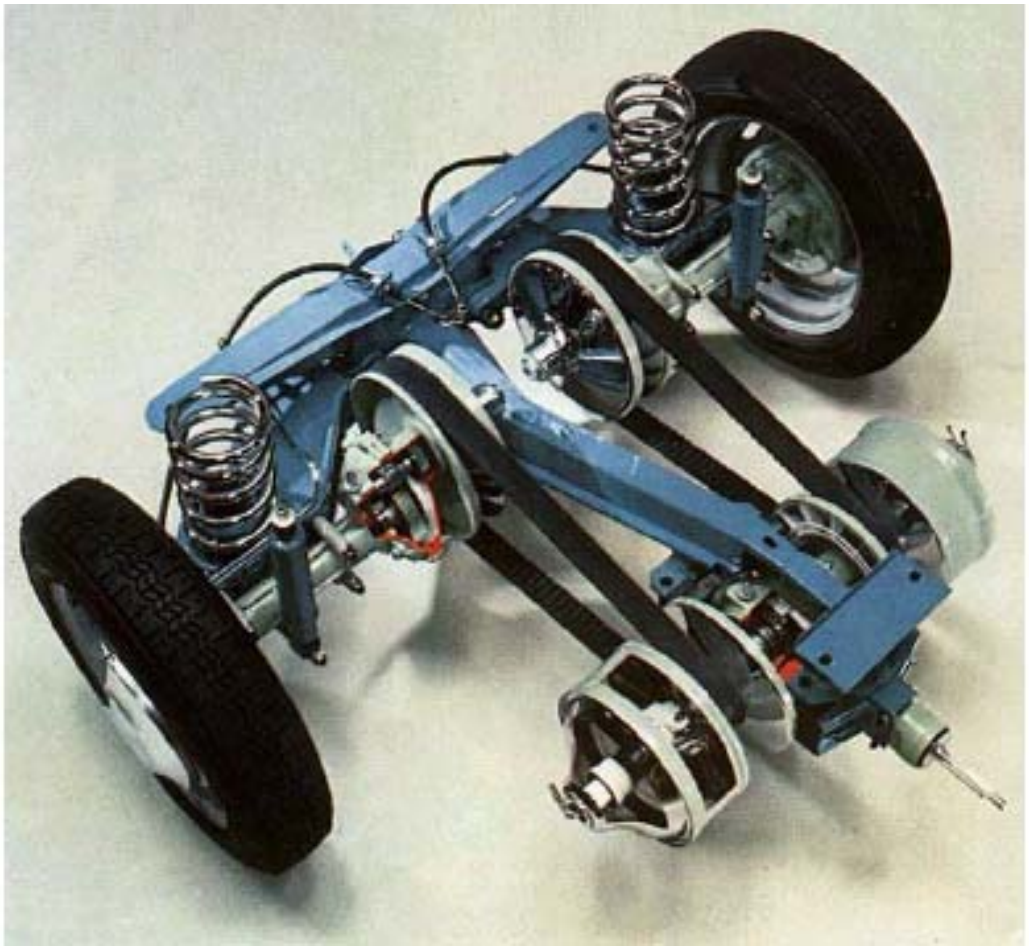
Large radius of flexible belt results in slower speed

Mid Ratio: Speed 1:1





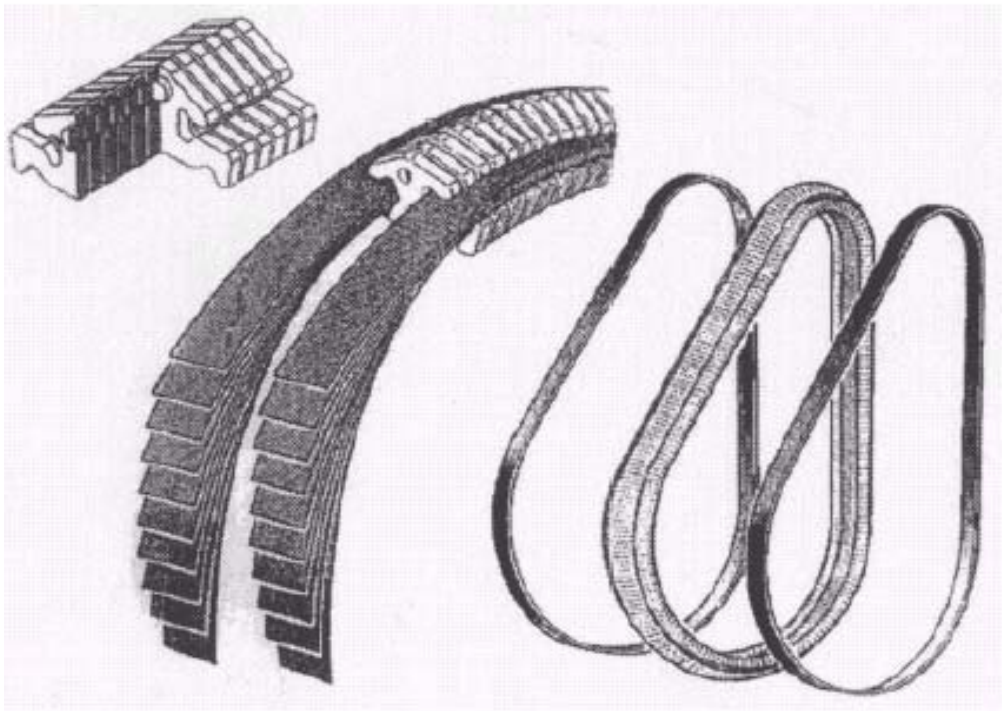
DAF Variomatic Rubber V-Belts



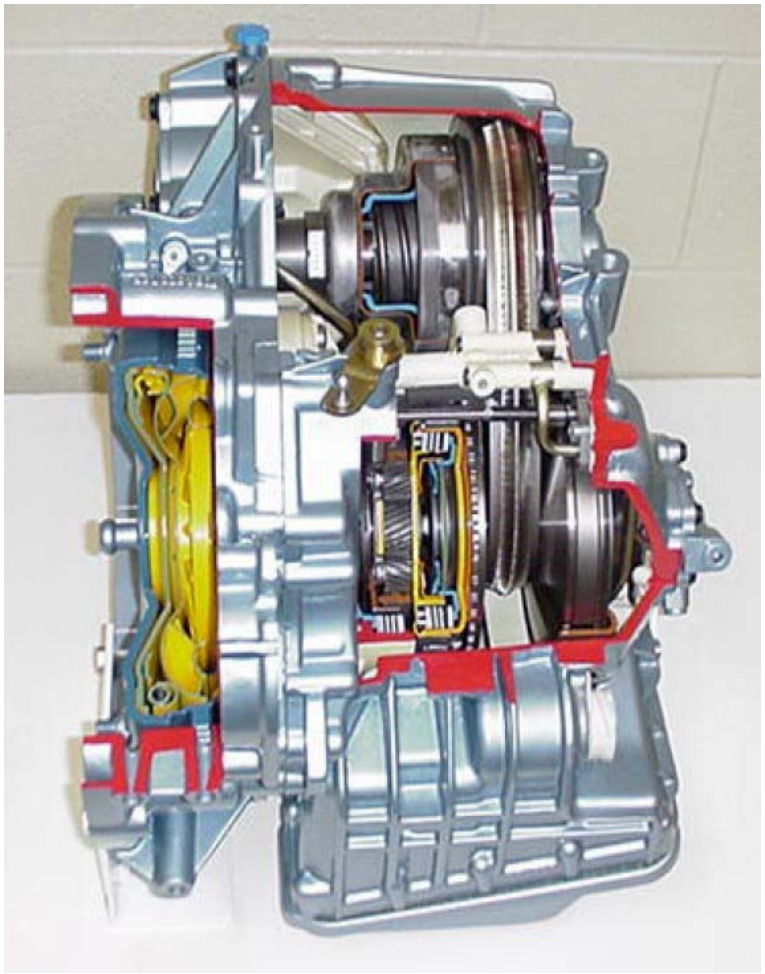
- Introduction in 1958
- Over 1 million DAF and Volv cars produced in 20 year period
- Shown is DAF 55 drive used with 1100 cc Renault engine from 1968

Metal V-Belt Construction

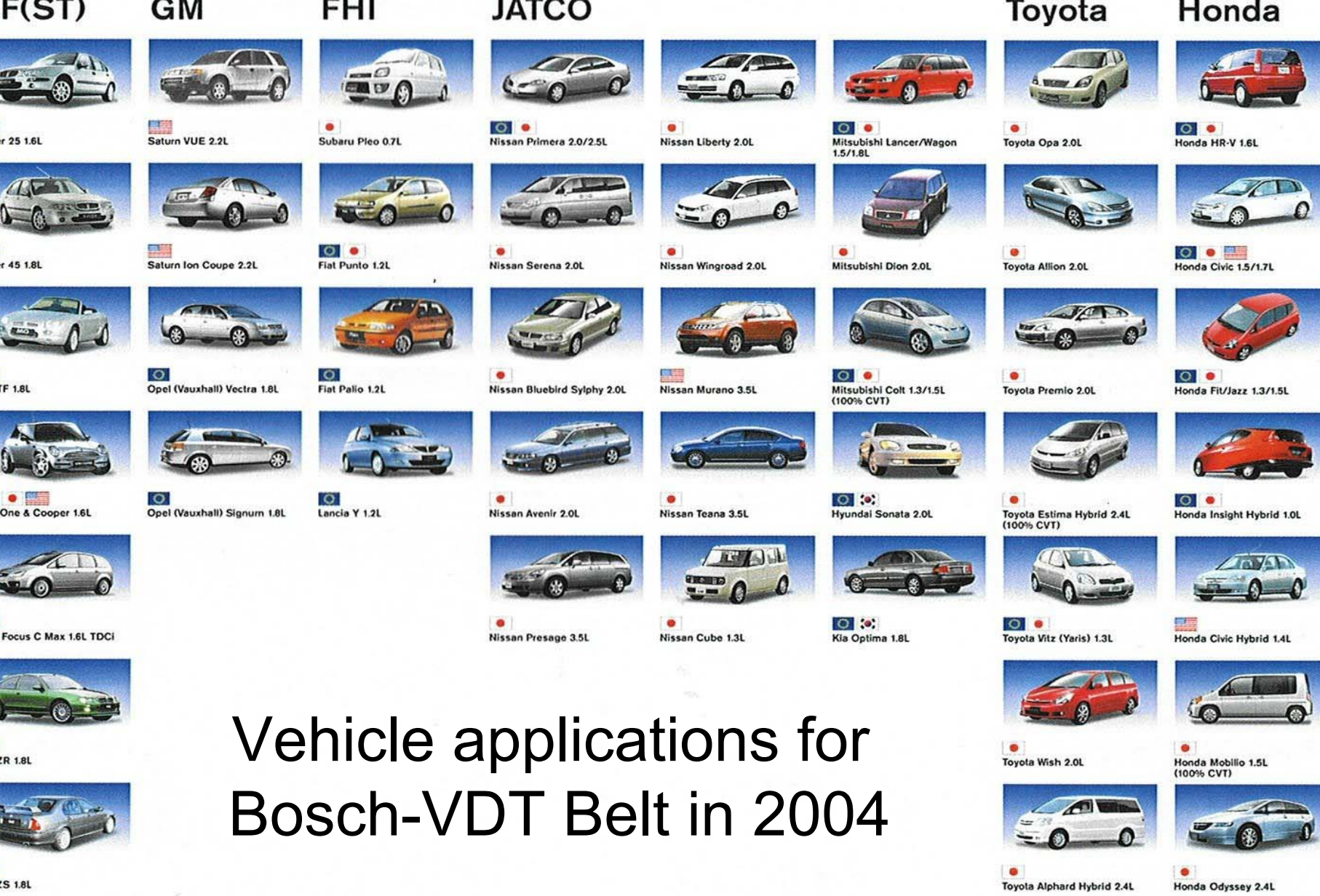
Introduced by Van Doorne's Transmissie in 1987



Metal V-Belt Transmission

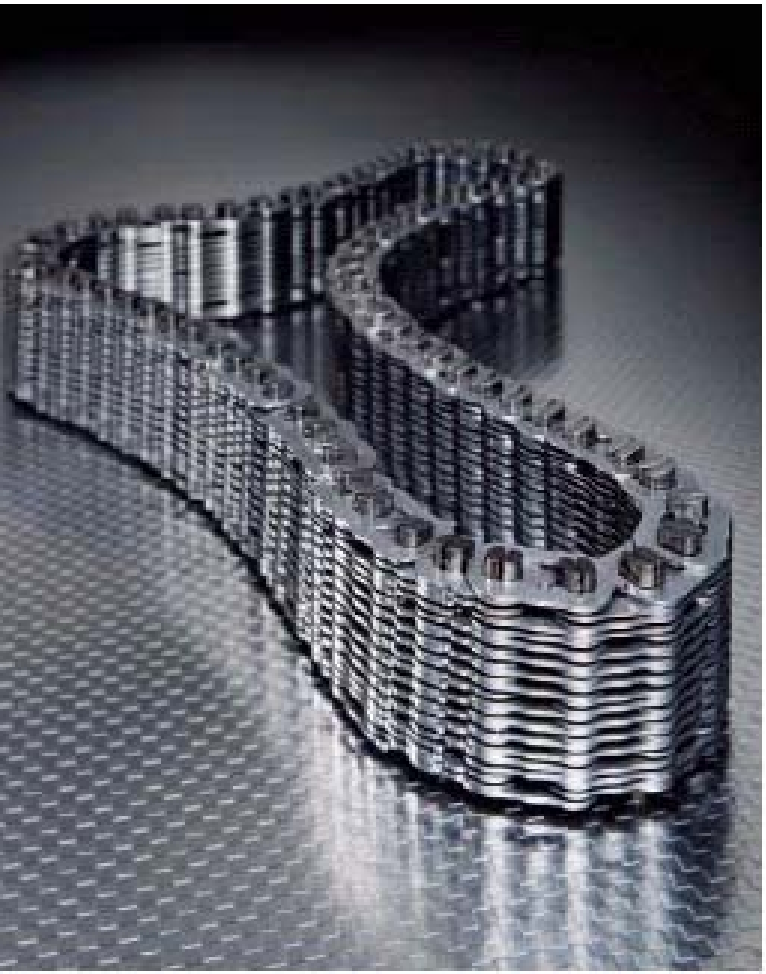


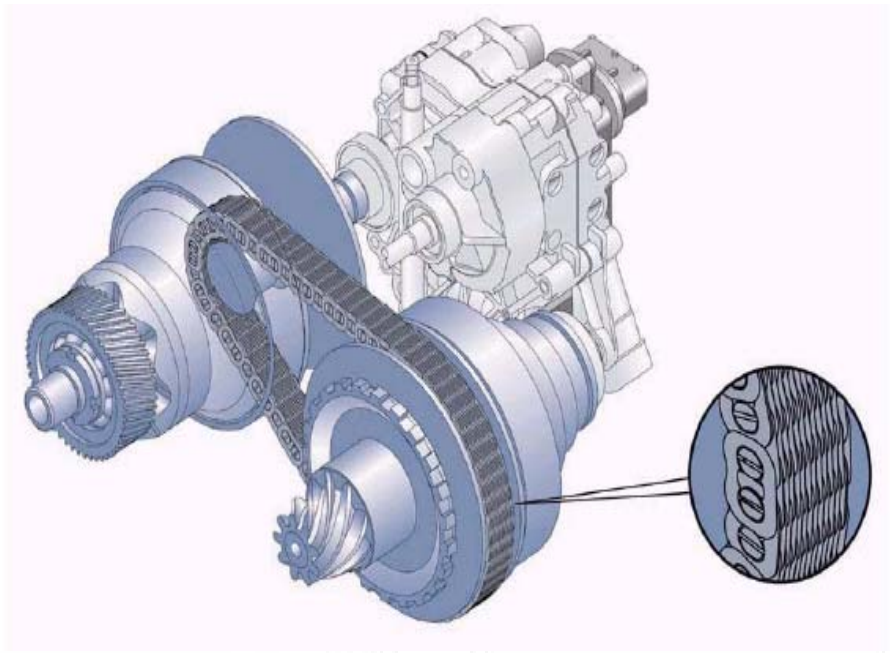
- Production from 1987-2000 about 3 million
- In the last 4 years about 4.5 million produced
- Example shown is a ZF –CFT23 with torque converter input



Vehicle applications for Bosch-VDT Belt in 2004

LuK/PIV-Reimers chain Audi Multitronic

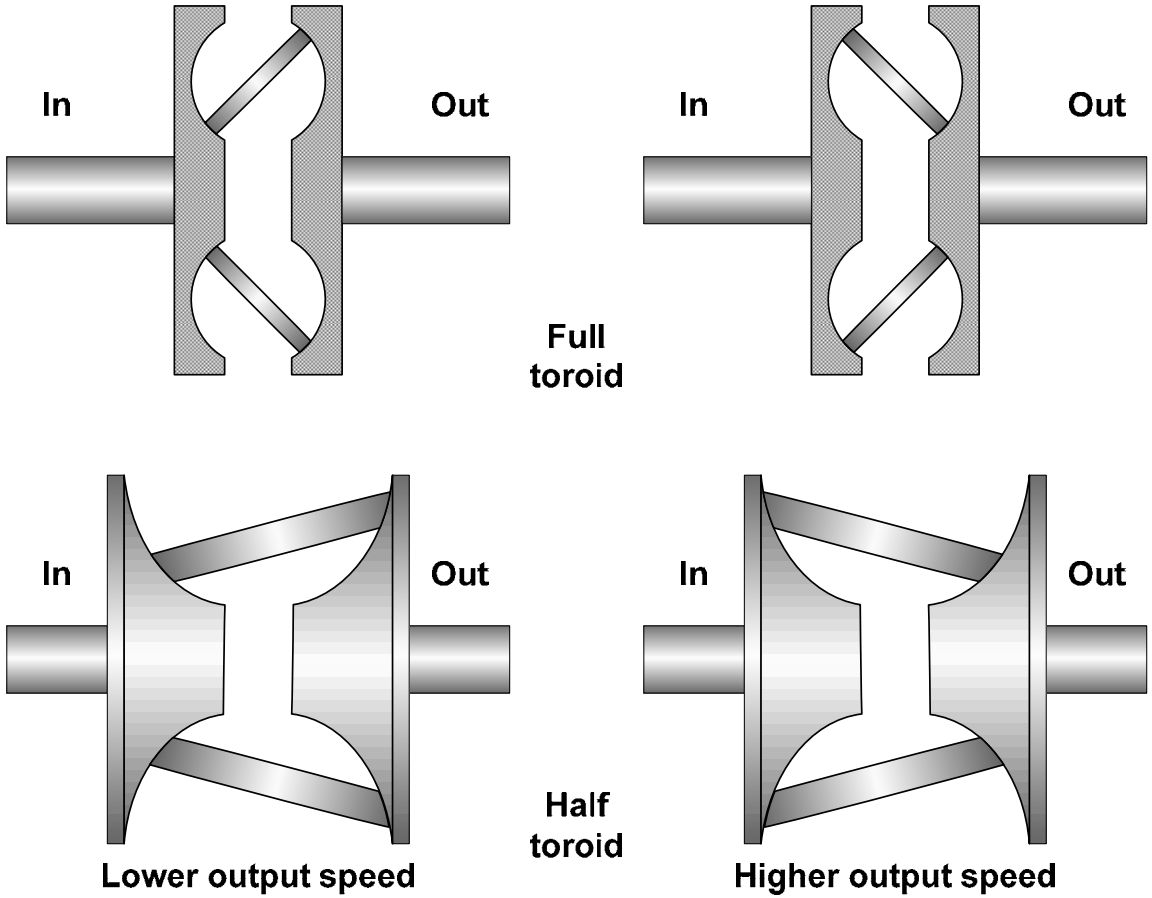




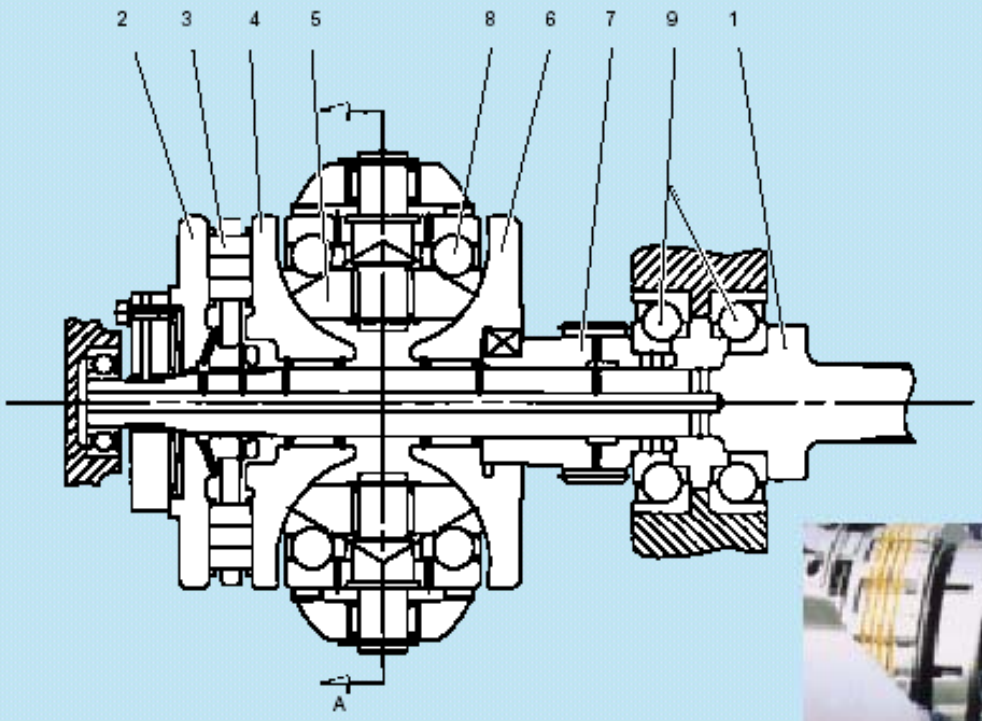
Traction Drives

- Many physical alternative layouts that give the mechanical geometry changes suitable to give a CVT.
- "Traction" requires transmission through a fluid film under elasto-hydrodynamic lubrication (EHL) conditions.

The Toroidal Drive Concept



Half Toroid Construction

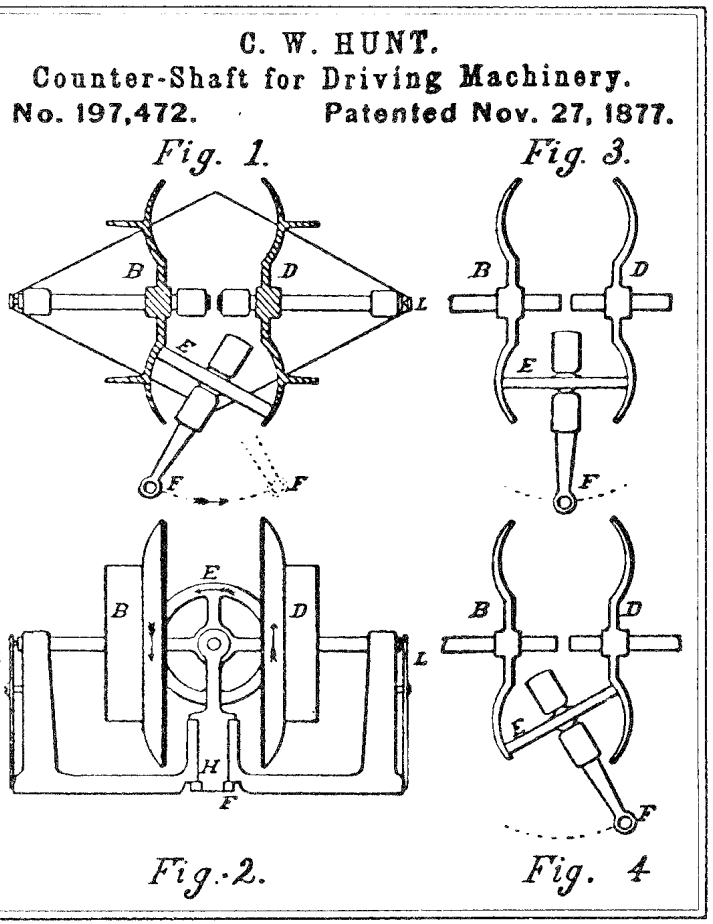


1. Input shaft
2. Loading cam
3. Cam roller
4. Input disk
5. Power roller
6. Output disk
7. Output gear
8. Power roller bearing
9. Disk sustaining bearing

Jatco/ NSK Half Toroid

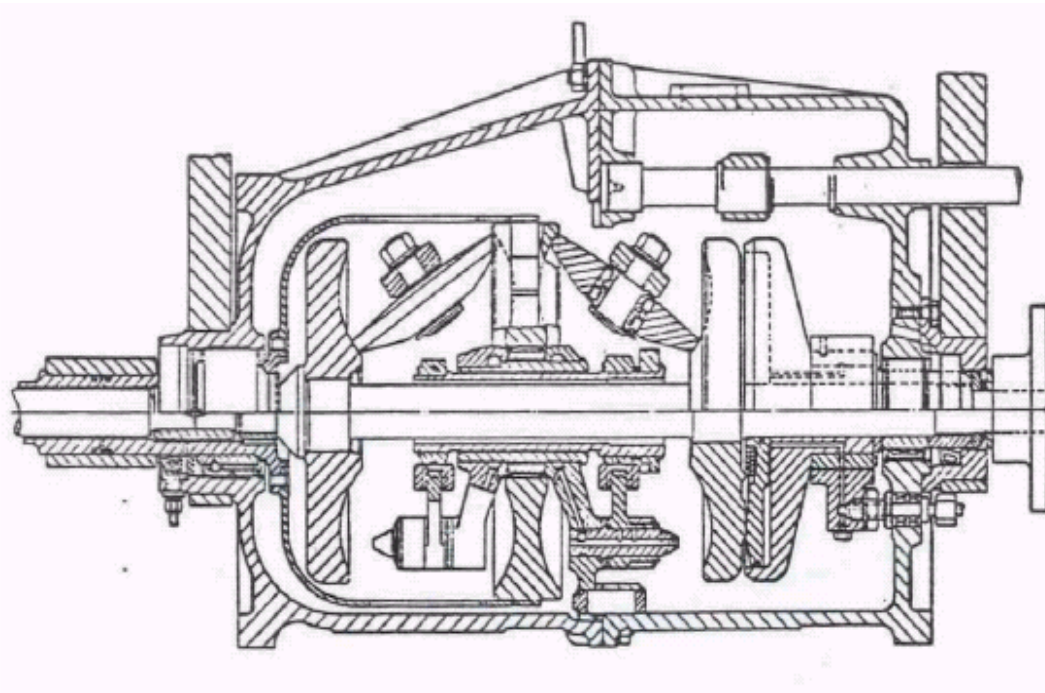
- Fitted as production item in Nissan Gloria and Cedric from 1999, home market only
- 3 L petrol engine
- Input rating 210 kW, and 390 Nm
- CVT ratio range 4.4:1
- Torque converter as a starting device
- Model upgrade in 2004

Full Toroid



Hunt Patent

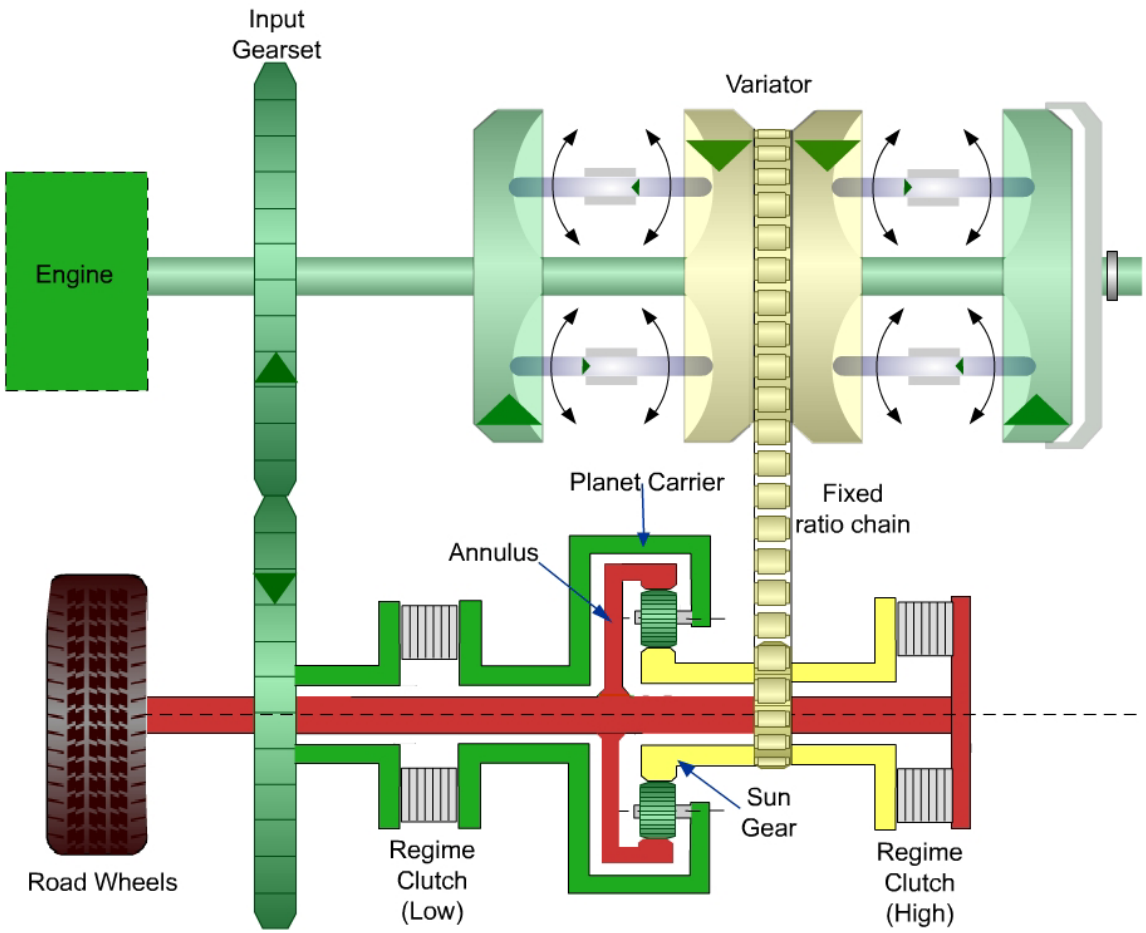
Hayes Variator



Full Toroid Transmission

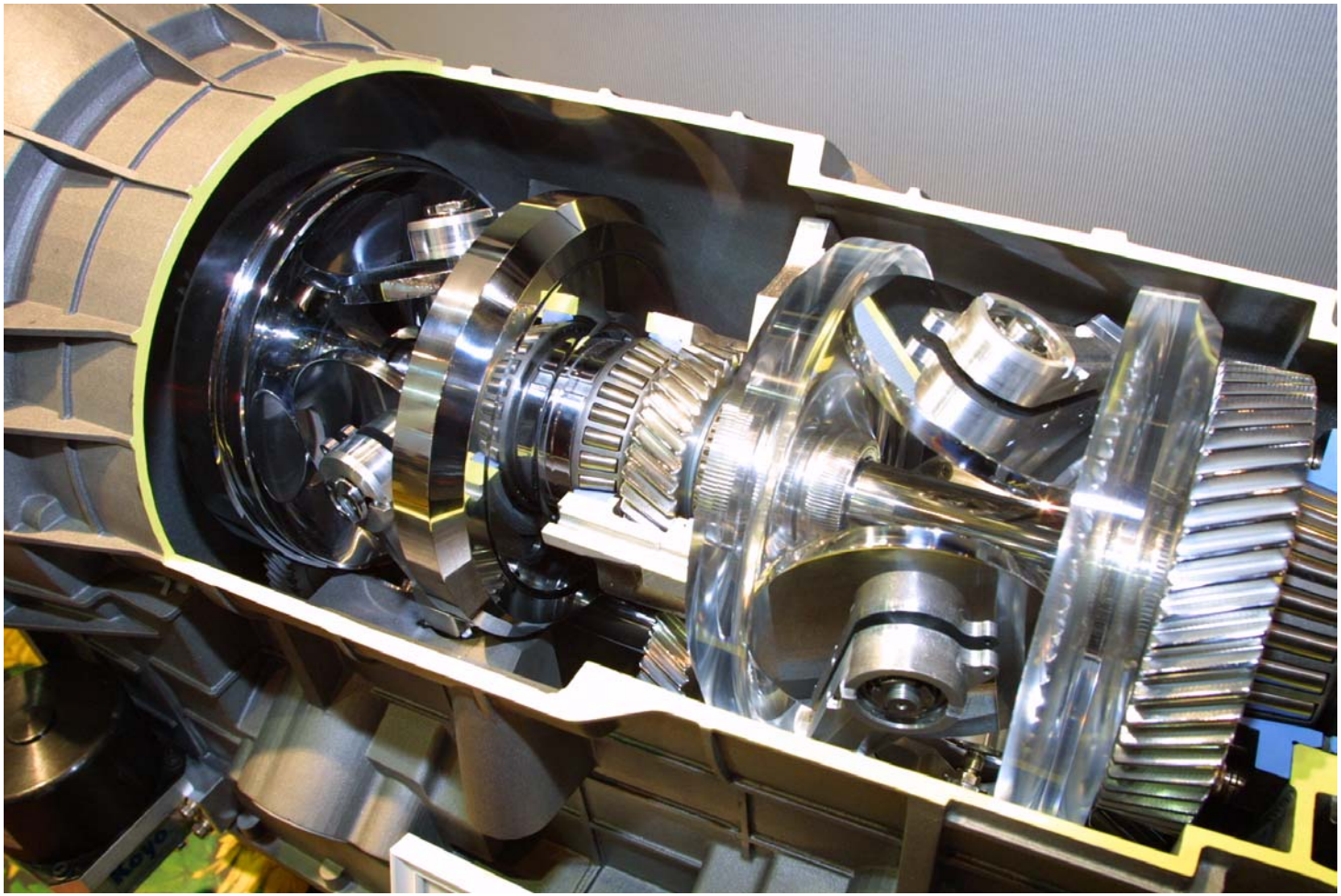
Austin 16
1932

Torotrak IVT Layout



Torotrak use a "split path" layout with an epicyclic gear on the output side. This gives a geared neutral and hence infinite ratio and also a reverse, hence is an IVT.

Torotrak IVT In-line Transmission



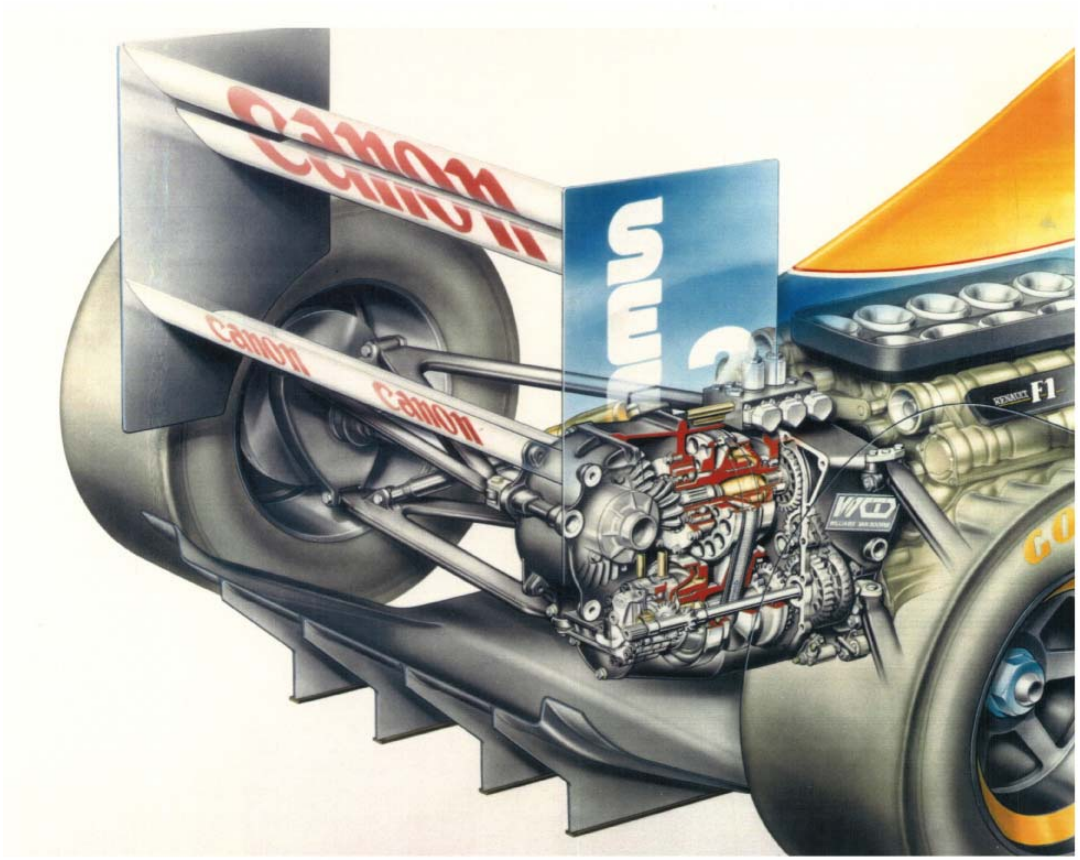
CVT Benefits

- No gear shift
- Continuous transmission of torque
- Control of engine speed independently of vehicle speed
- Ability to operate engine at peak power over wider range of vehicle speeds
- Ability to operate at most fuel efficient point for required output power

Control Objectives

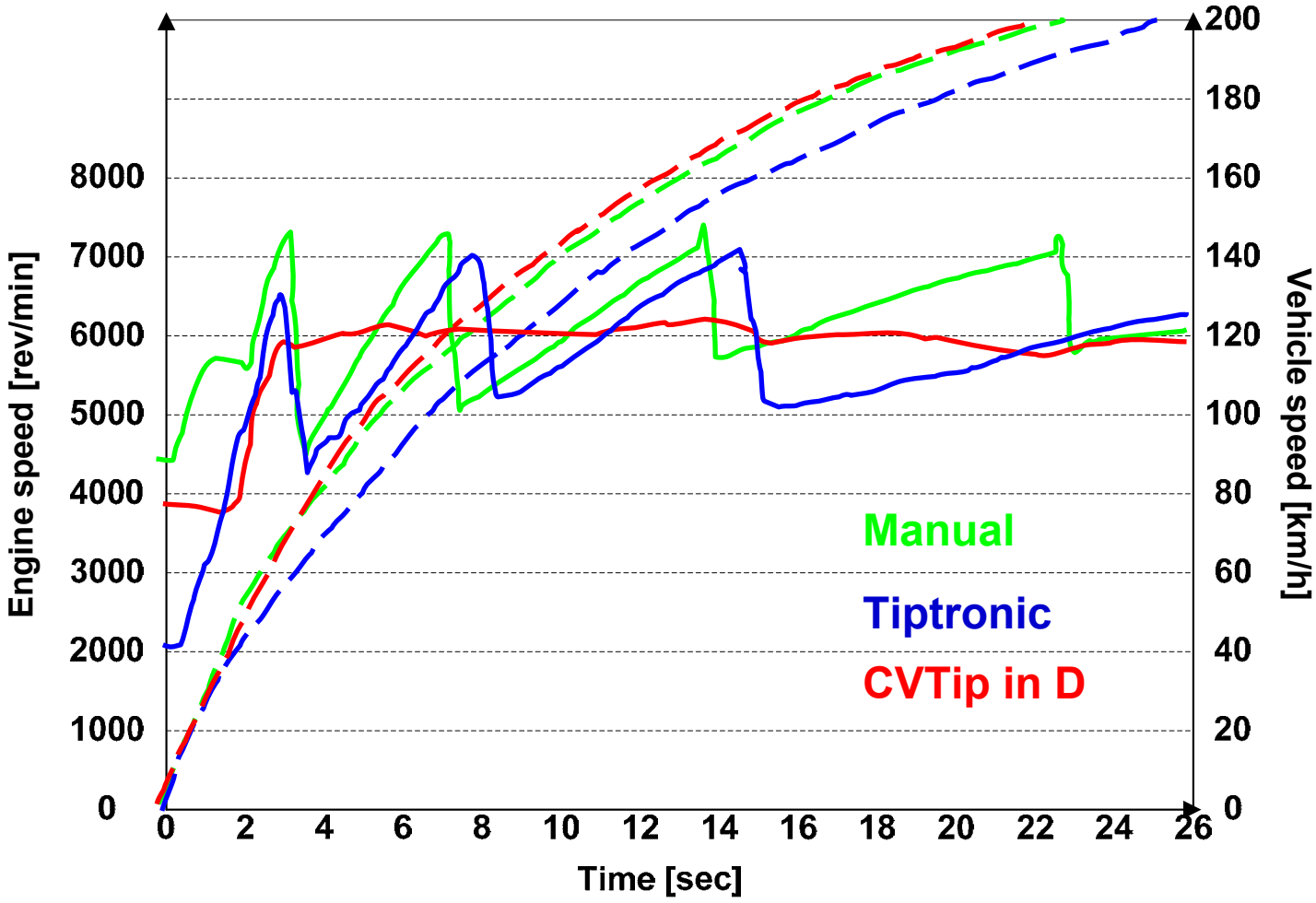
- Good fuel economy
- Good driver feel – driveability
- Easy driving as an automatic
- Comfort and smoothness for passengers
- Performance – acceleration capability
- Electronic control enables these

Williams (FW 15C) Van Doorne LG1



- Power: 600 kW
- Input speed: 15 000 rev/min
- Input torque: 600 Nm
- Ratio range: 2.5:1
- Pulley centres: 160 mm
- **FIA ban: 1993**

Acceleration Comparisons: Porsche Boxster



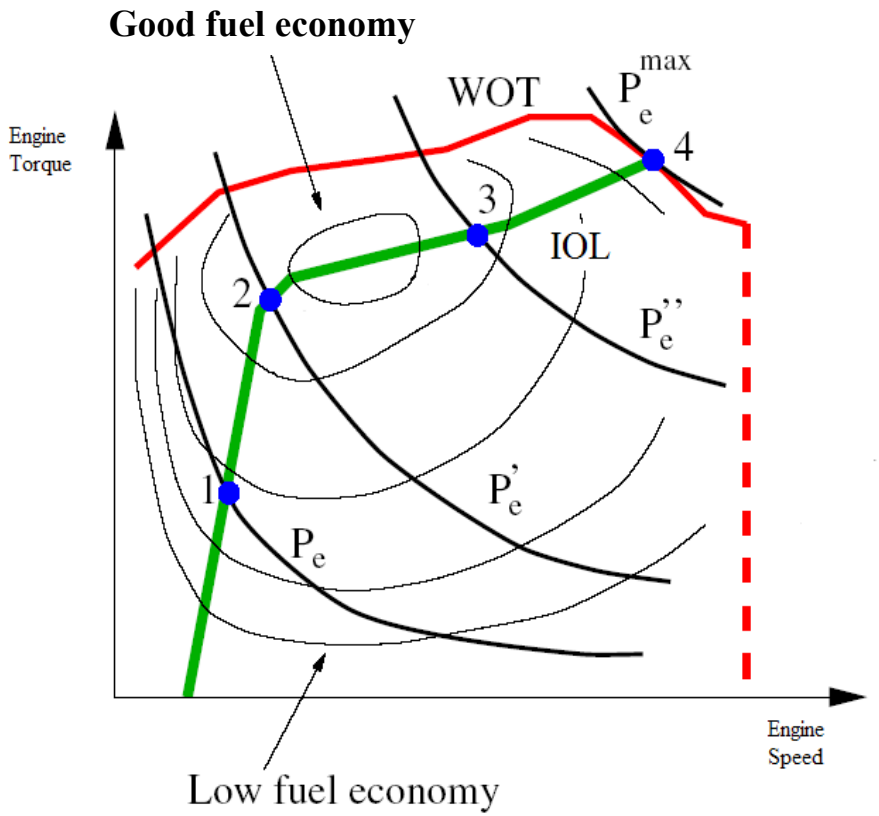
CVT Disadvantages

- Mechanical efficiency of variator
- Parasitic efficiency of transmission system and controller
- Compromise between fuel economy and torque margin to achieve driveability (avoid elastic band feel)

CVT Efficiency

- All CVT variators have losses due to the power transfer which appears as a speed or slip loss across the variator
- CVTs are hydraulically controlled and the pump takes power as in a conventional automatic transmission
- Efficiency is more variable for CVT than geared discrete ratio systems

Engine map



WOT- wide open throttle (maximum torque line)

IOL – ideal operating line, gives best economy for CVT operation

Wide ratio range needed to achieve ideal engine operation

Fuel Consumption Figures

Comparison of fuel consumption figures for CVT relative to equivalent automatics shows a 5-10% improvement for 4 to 5 ratio variants.
However, the table shows comparison for equivalent **manual** transmission vehicles over the European Drive Cycle (+ve in red is worse)

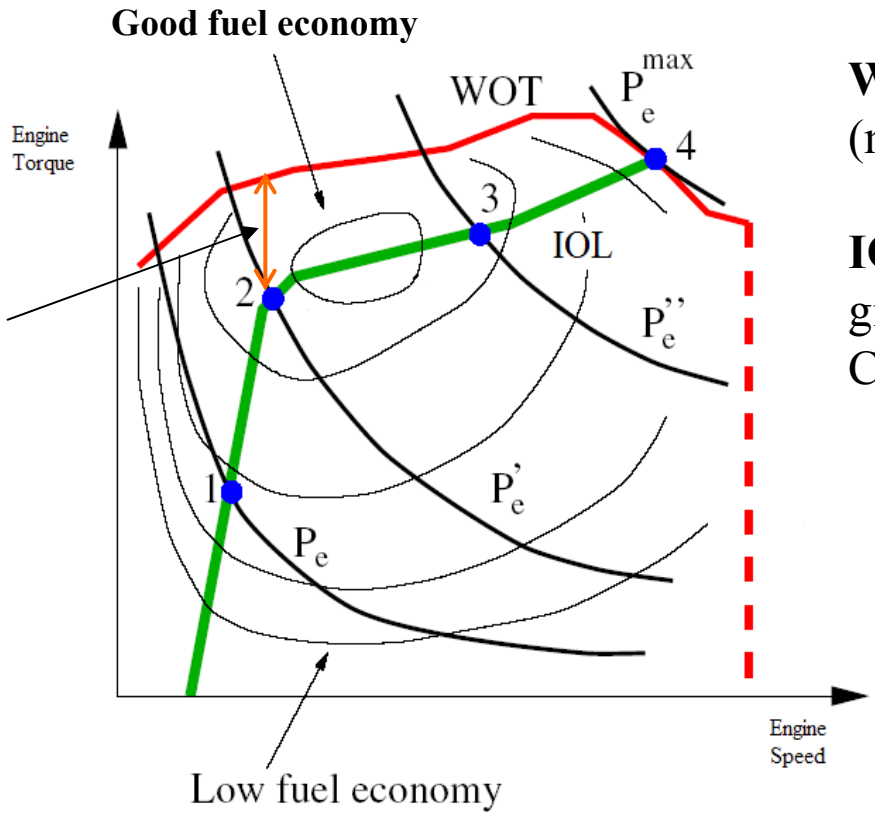
Urban	12%	22.7%	10.5%	8.1%	10.4%	6.1%	-4.8%	-5.0%
Extra-urban	13.8%	12.1%	10.0%	-3.9%	0.0	4.8%	-1.3%	5.0%
Combined	13.2%	16.4%	8.3%	1.7%	4.9%	4.9%	-2.3%	0.0

Driveability Compromise

- Driveability describes the longitudinal dynamic behaviour of a vehicle in response to driver inputs, in a comprehensive range of driving situations, and the related driver subjective perception of that behaviour

- Less torque available immediately with a CVT than with a gear transmission

Driveability Compromise



Torque margin

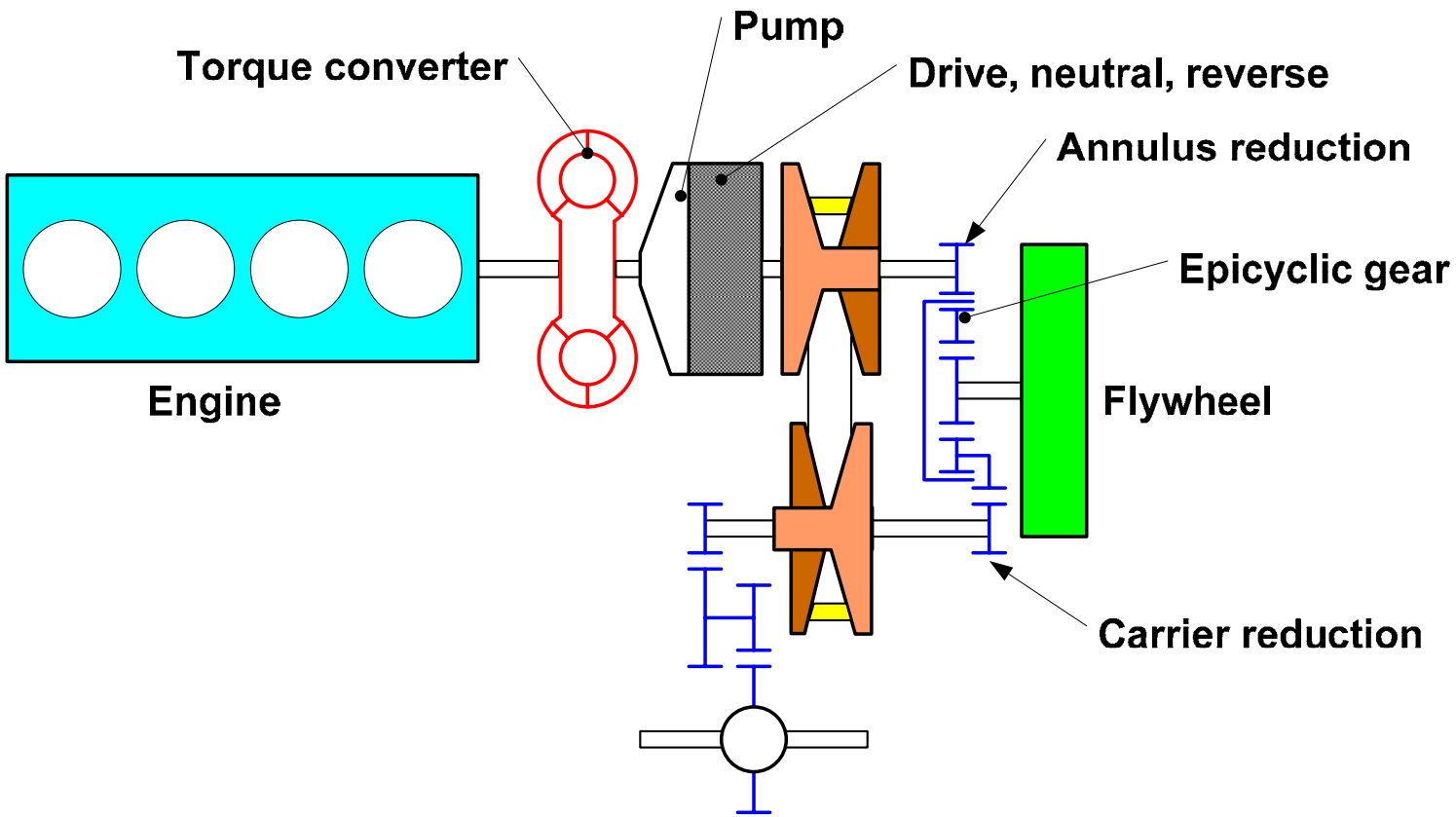
WOT- wide open throttle (maximum torque line)

IOL – ideal operating line, gives best economy for CVT operation

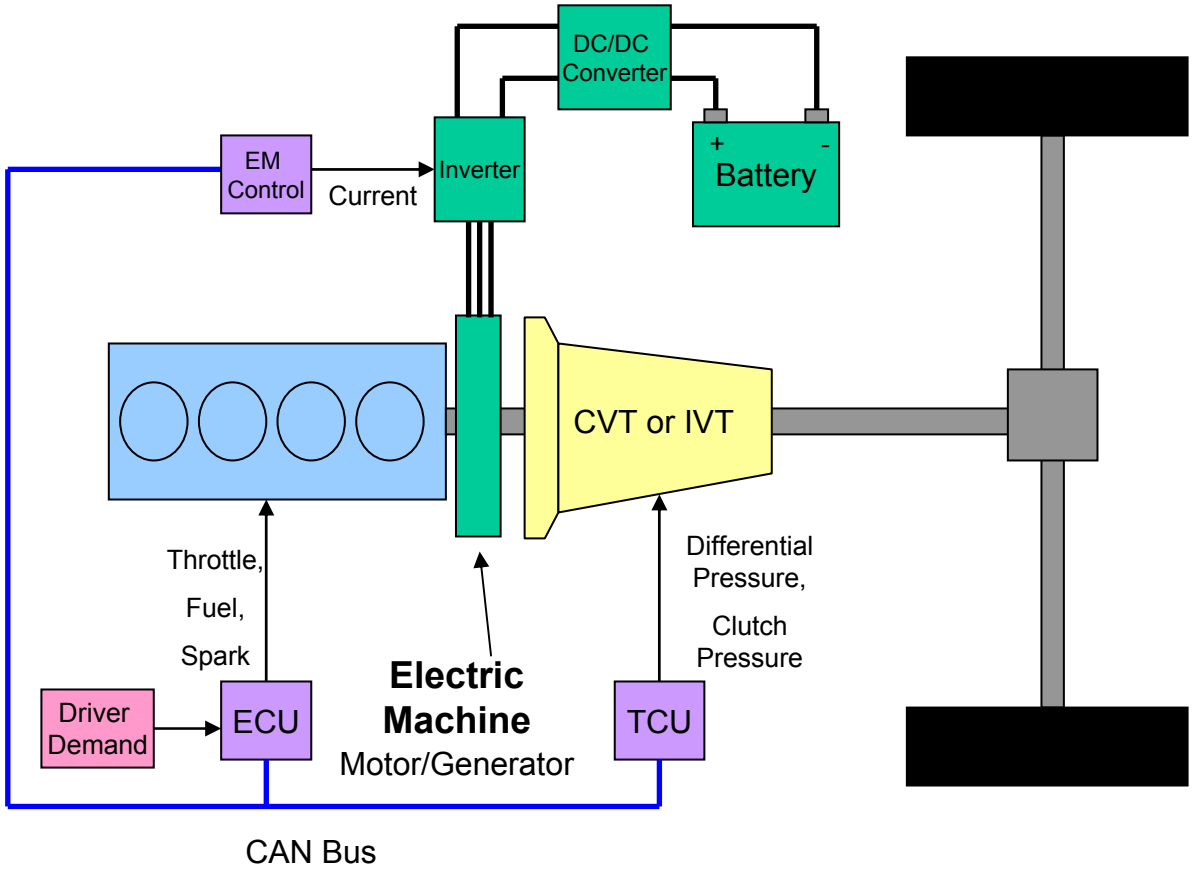
Solutions for Improved Driveability

- Torque boosters
  - flywheel
  - integrated electrical machine (motor/generator)
- Control – modified calibration
- Match the CVT with the most appropriate engine
- Modify engine characteristics to those of the transmission by design and/or control

Zero Inertia Concept



CVT Mild Hybrid Architecture



Engine Matching

- Diesel engines have higher torque and lower speed range than petrol
- Modify engine systems to develop higher torque at low speeds – interest in this as engine downsizing for conventional transmissions too
- Use of lean burn techniques to operate engine more efficiently at higher speeds – experimental studies have shown both improvement in steady fuel consumption and transient response
- Development of homogeneous charge compression ignition (HCCI) and controlled auto ignition (CAI) is also appropriate for CVTs

Market Share in 2004

Region	Manual	Automatic	CVT
Europe	84%	14%	2%
N. America	9%	90%	1%
Asia	40%	52%	8%
Japan	20%	65%	15%

Market Predictions

- ZF – increase from 2% share of sales in 2002 to 4.4% in 2012
- ZF – CVT will occupy 10 % of market for automatic transmissions in 10 years
- Jatco – increase from 8% share of sales in 2003 to 45% by 2010
- CSM Worldwide – increase in N. America to 3% by 2009

Comments

- CVT has a bright future
- Market share increasing
- Research and development still required
  - Improve efficiency
  - Torque booster
  - Engine integration
  - System control

- CVT driveability is key to customer acceptance, particularly in Europe
- CVTs share some driveability characteristics with hybrid vehicles
- Control and calibration with new concepts and an integrated approach to total powertrain calibration can give driveability solutions