

An Introduction to Hydro-mechanical Transmissions

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(Previously titled: “Cost Savings With Hydro-mechanical Transmissions”)

Introduction

Hydro-mechanical transmission architectures are growing in popularity as a cost effective means to provide continuously variable transmission (CVT) functionality in the heavy-duty off-road market segment. This presentation will introduce the audience to the basics of operation and commonly used terms.

- Topics Covered:
 - Speaker Background
 - Simple Hydro-mechanical Transmission Schematic
 - Current Industry Examples
 - Important Design Characteristics
 - How Fuel Is Saved
 - Other Beneficial Characteristics
- Caveats:
 - Not A Design Guide
 - Limited To Off-road Perspective

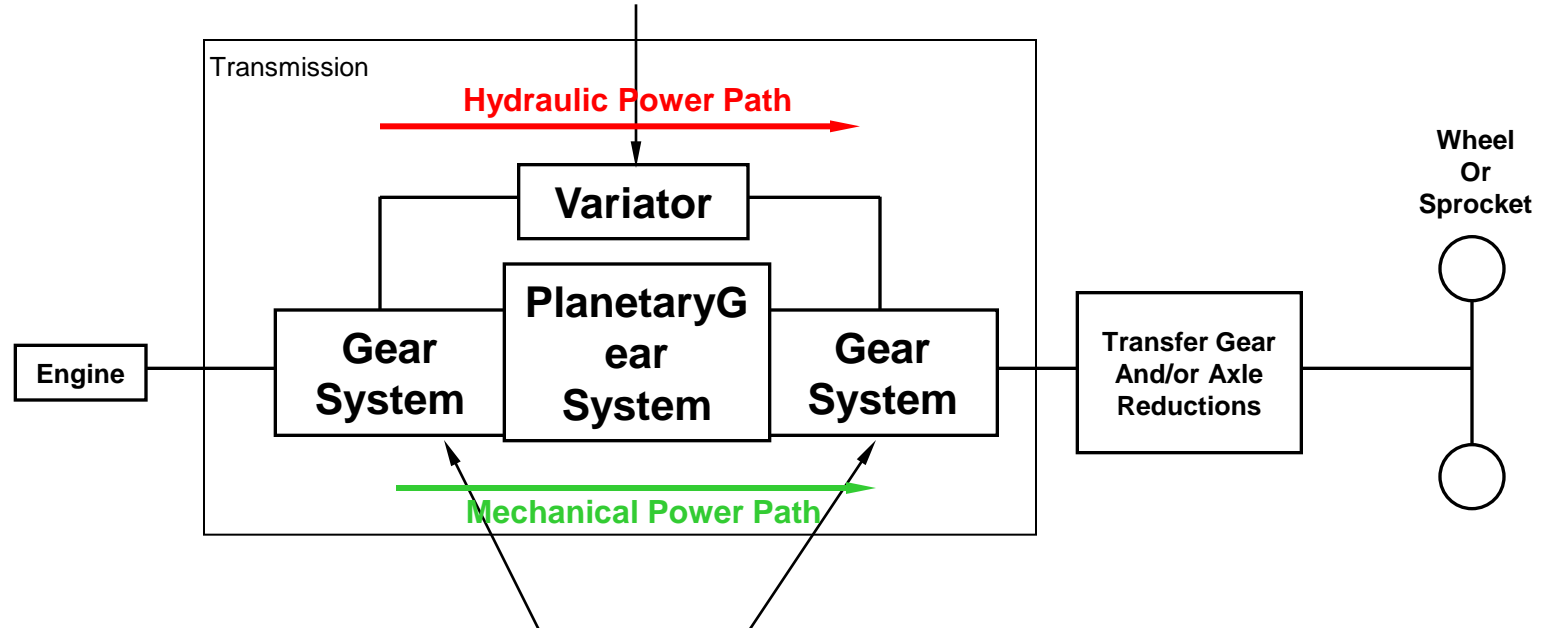
Mike Cronin's CV

- Joined Caterpillar upon graduation from Michigan State University with a BSME in 1973
- Entire career working on off-road drivetrain performance and design:
 - Hydro-mechanical transmissions for a broad range of applications
 - Electric drive for TTT
 - TTT & Belted machine steering systems and components
 - Assorted lower powertrain projects
 - Assorted powershift transmission concepts
- Drivetrain related patents
 - 23 Granted
 - 10 Pending
 - 9 Notifications
- Retired in 2010
- Rejoined Caterpillar's Drivetrain Research Dept on a part time basis to continue work on hydro-mechanical drivetrains.

General Parallel Path Transmission Schematic

a.k.a. Split Torque, Power Split, Hydro-mechanical, Electro-mechanical etc.

- A variator is a device that can vary the speed or torque ratio across its two shafts in a continuous manner.
- Several types are available: hydraulic, electric, traction etc.



- In addition to gears these systems may contain clutches, brakes or other familiar transmission components connected in various ways.
- A very large number of combinations are possible.

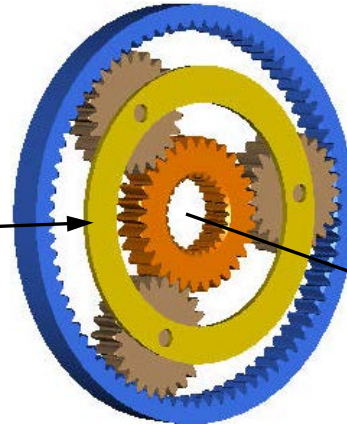
There must be at least one planetary

Planetaries Are Splitters and Adders

General Planetary Gear System

Torque Splitter

Torque



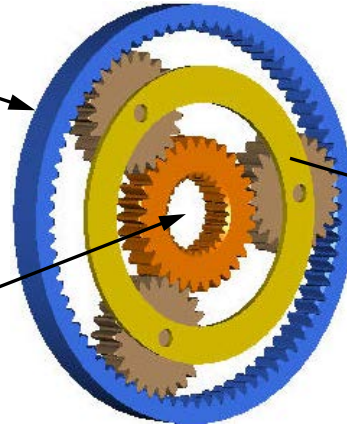
Output Torque1 = $A \cdot \text{Torque}$

Output Torque2 = $B \cdot \text{Torque}$

Speed Adder

Speed 1

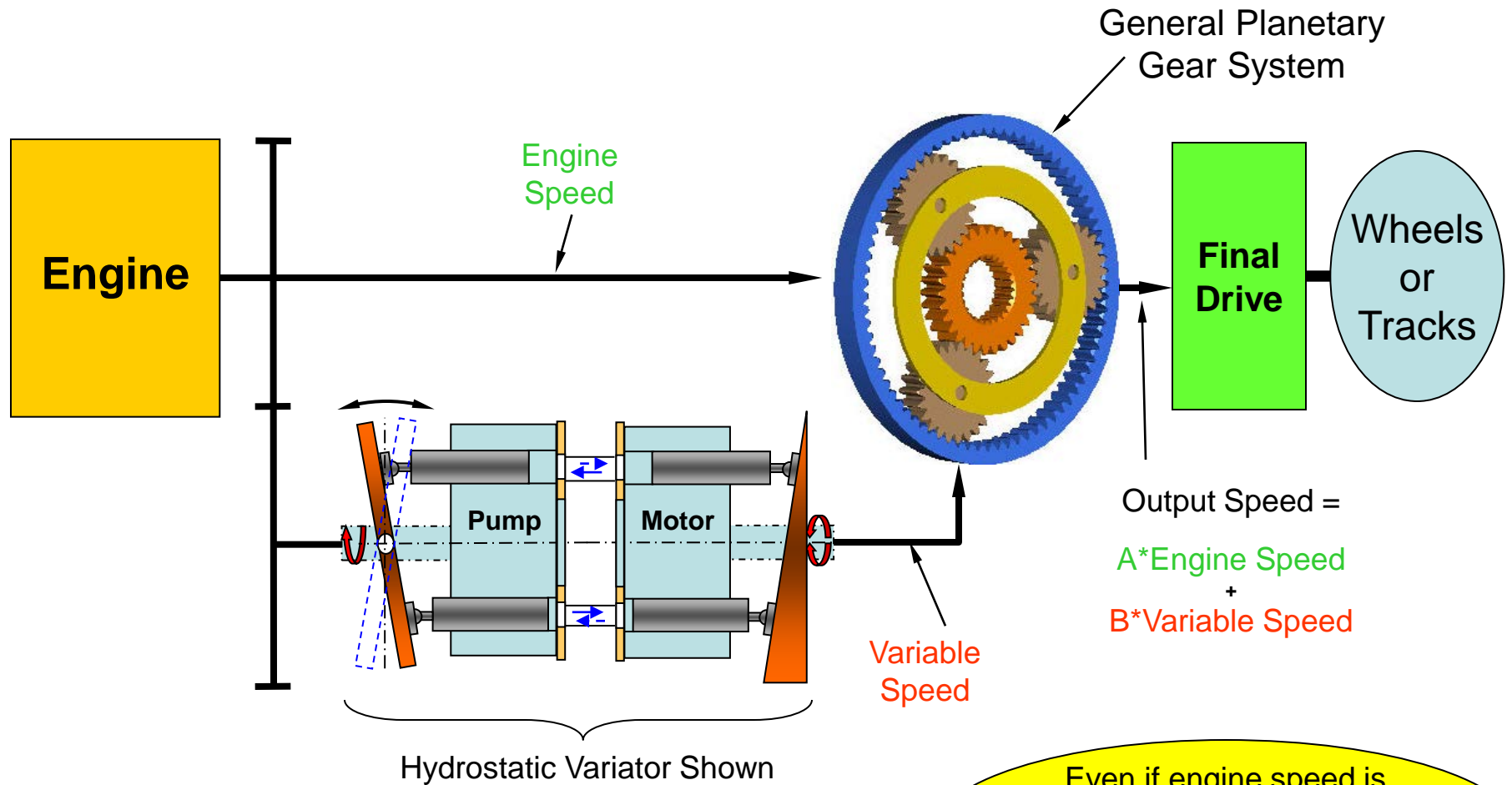
Speed 2



Output Speed = $A \cdot \text{Speed1} + B \cdot \text{Speed2}$

Output speed is the sum of the input speeds.

Hydro-Mechanical CVT



Even if engine speed is constant, if the other speed is variable then the output speed is still variable.

Why choose hydro-mechanical?

- Scaling
 - Variators are only available in a limited number of sizes.
 - A given size variator matches to a larger machine when used in a hydro-mechanical configuration.
 - Larger machines now have access to CVT behavior.
- Efficiency
 - The power path carries a fraction of engine power
 - Less hydraulic power means fewer losses.
 - Less fuel
 - More power to ground
- Cost
 - Most cost effective CVT technology for 200-400 hp wheel loaders.

Hydro-mechanical Transmission Examples

AG



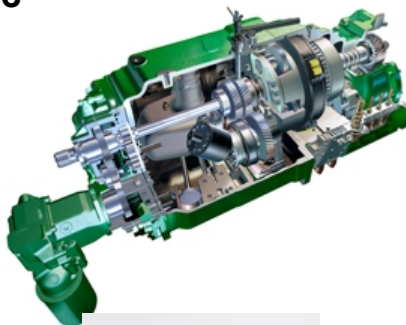
Vario



Eccom/IVT/S-matic



IVT



IVT

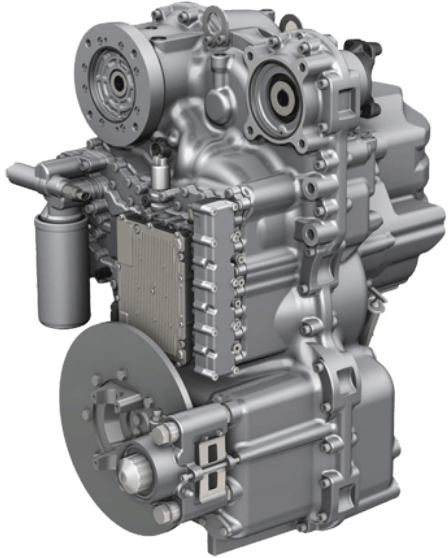


CVT

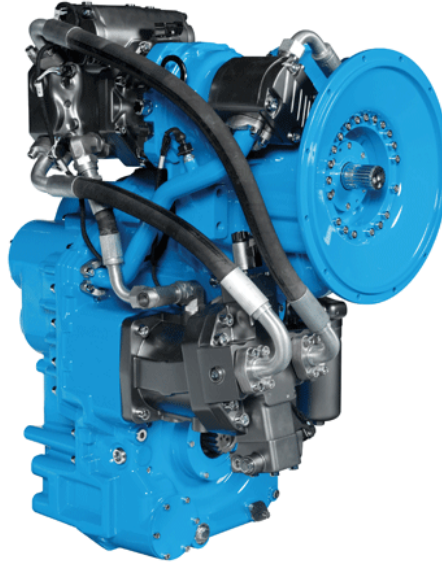


Hydro-mechanical Transmission Examples

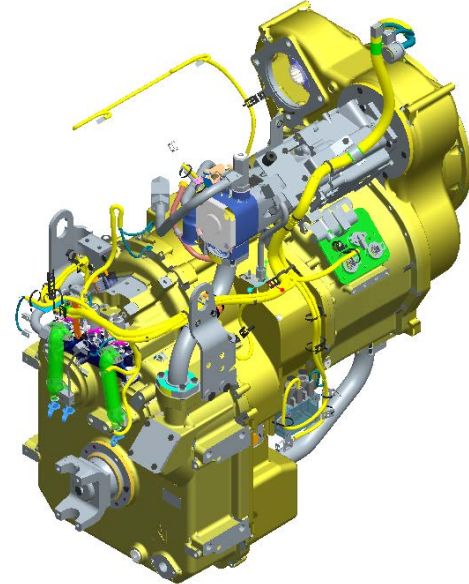
Wheel Loader



ZF
cPower



Dana/Rexroth
HVT



Cat
CVT

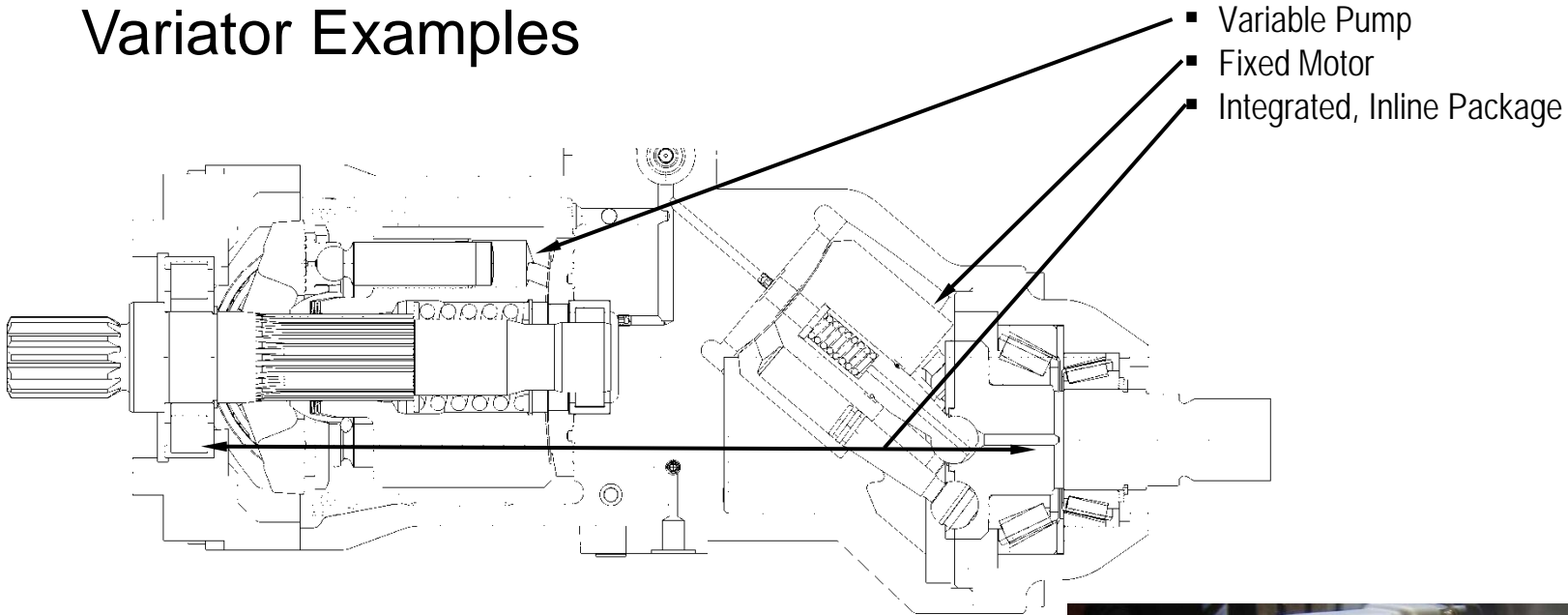


Important Design Differentiators

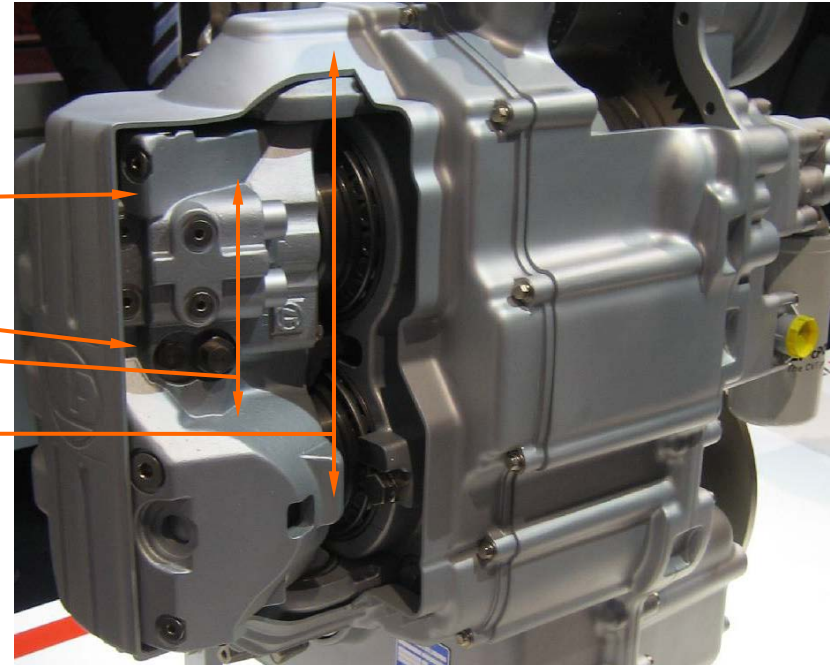
- Variator Type
 - Discussed Above
- Coupling Type
 - Input
 - Output
 - Compound Split
- Number of Ranges or Modes
 - One
 - Two
 - Three
 - Four



Variator Examples



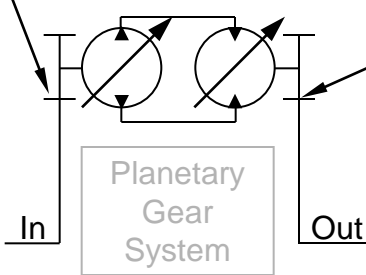
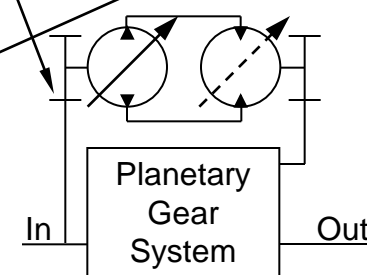
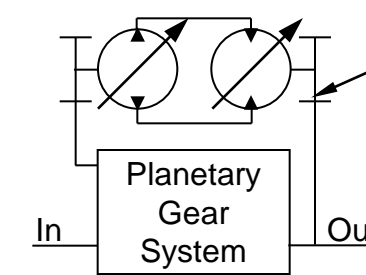
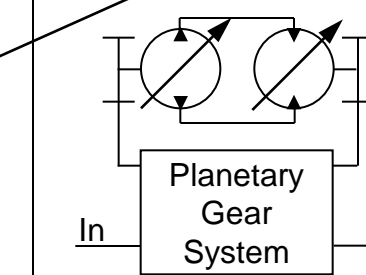
- Used in ZF Designed cPower Shown @ 2010 Bauma
- Variable Pump
- Variable Motor
- Pump and Motor Displacements Linked
- Motor Displacement Decreases while Pump Displacement Increases
- Integrated, U Package



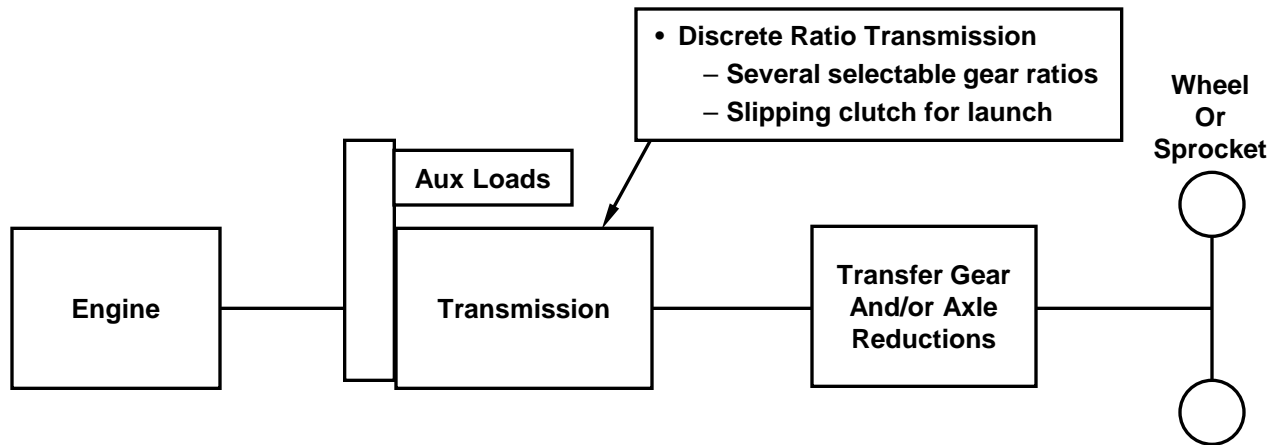
Explaining the term “Coupled”

The Variator is Coupled to the Input

The Variator is Coupled to the Output

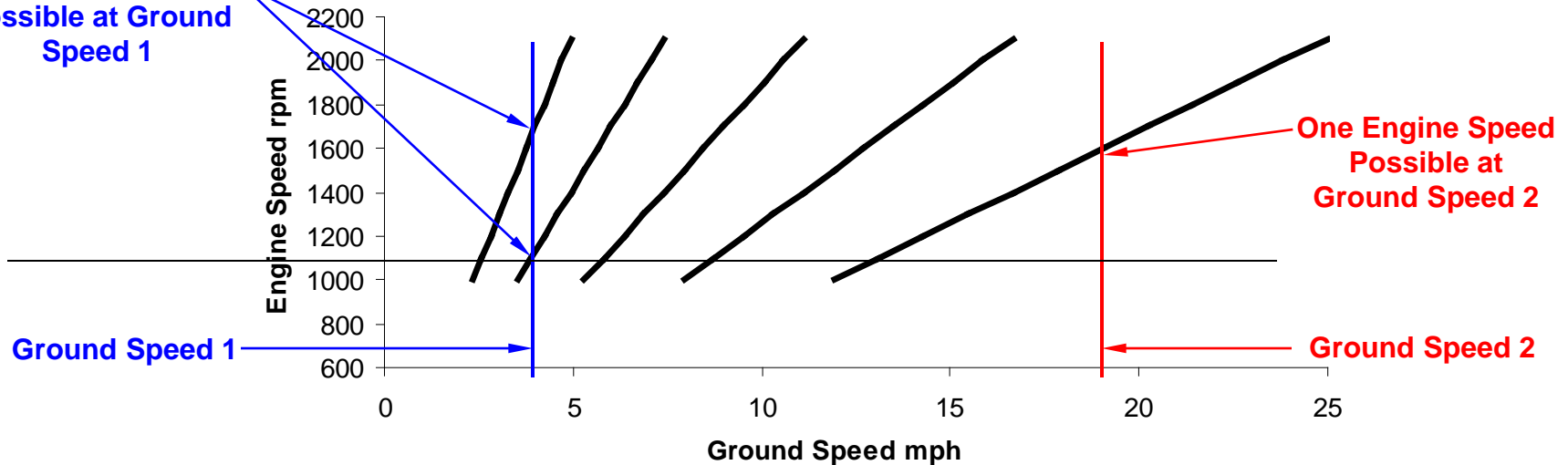
	Double Coupled / Unsplit	Input Coupled / Output Split	Output Coupled / Input Split	Uncoupled / Compound Split
	 <p>In</p> <p>Planetary Gear System</p> <p>Out</p>	 <p>In</p> <p>Planetary Gear System</p> <p>Out</p>	 <p>In</p> <p>Planetary Gear System</p> <p>Out</p>	 <p>In</p> <p>Planetary Gear System</p> <p>Out</p>
Hydraulic Variators	<p>914</p> <p>ST125 1st</p> <p>Rexroth HVT 1st</p>	<p>Cat CVT</p> <p>JD 6000, 7000 IVT</p> <p>S-Matic</p> <p>Graziano</p> <p>Fiat/Ag</p> <p>ZF Eccom</p> <p>Rexroth HVT 2nd, 3rd</p>	<p>Vario</p> <p>8000 IVT 1st, 3rd</p> <p>ZF CP</p>	<p>8000 IVT 2nd, 4th</p> <p>ZF CP 2nd, 3rd</p>
Electric Variators	<p>D6E</p> <p>D7E</p> <p>795AC</p>	<p>Volt</p>	<p>Prius</p> <p>Dual Mode/AHSII/EP40 1st</p>	<p>Dual Mode/AHSII/EP40 2nd</p>

Discrete Ratio Powertrain Schematic



Engine Speed vs Ground Speed
w Discrete Step Transmission

Two Engine Speeds
Possible at Ground
Speed 1

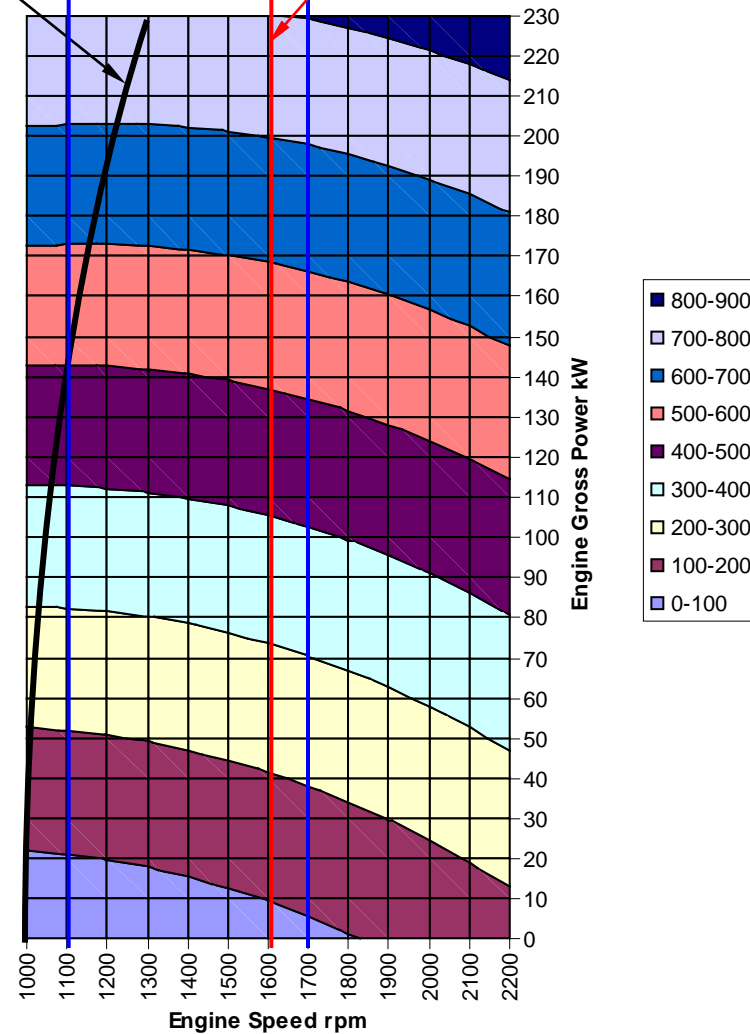


Ground Speed 1

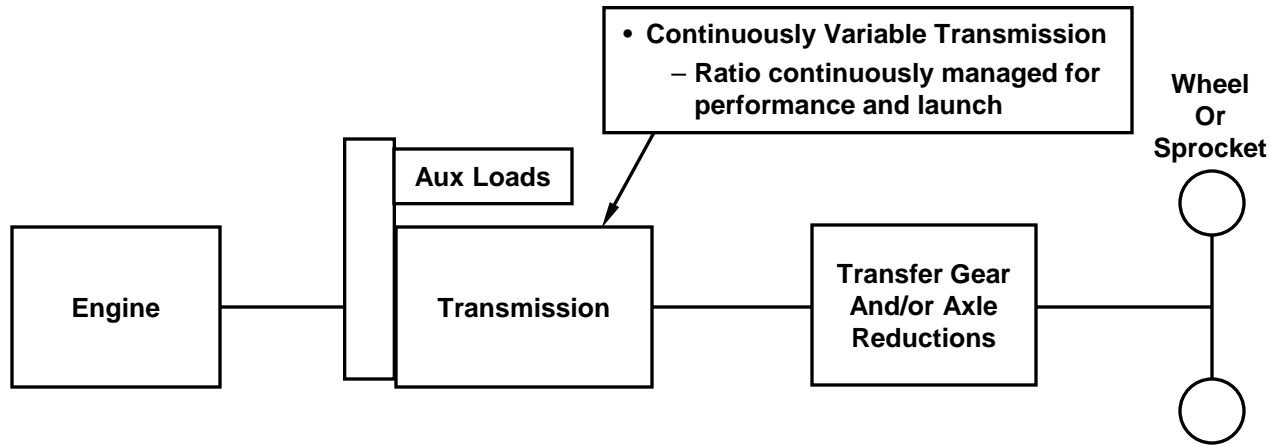
Ground Speed 2

Approximate Minimum
Fuel Consumption

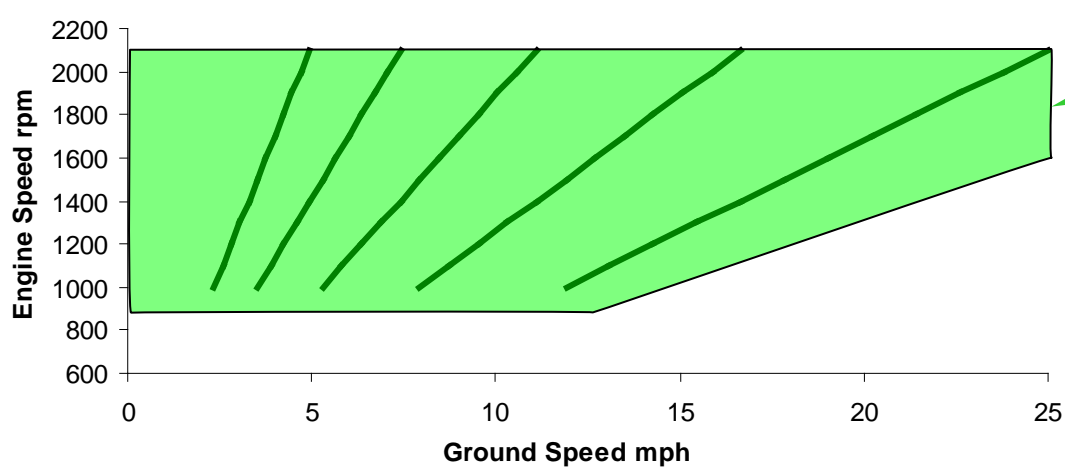
Hypothetical Engine Fuel Rate Contours
g/min



Continuously Variable Ratio Powertrain Schematic



Engine Speed vs Ground Speed



Any Engine Speed Possible at Any Ground Speed

Functional Definition of CVT:

Engine speed can be placed and maintained at the desired level regardless of ground speed.

