Continuously Variable Transmission (CVT)

A Timeline of CVT Innovation
• 1490 - da Vinci sketches a stepless continuously variable transmission
• 1886 - first toroidal CVT patent filed
• 1935 - Adiel Dodge receives U.S. patent for toroidal CVT
• 1939 - fully automatic transmission based on planetary gear system introduced
• 1958 - Daf (of The Netherlands) produces a CVT in a car
• 1989 - Subaru Justy GL is the first U.S.-sold production automobile to offer a CVT
• 2002 - Saturn Vue with a CVT debuts; first Saturn to offer CVT technology
• 2004 - Ford begins offering a CVT
Basics of Transmission

- The job of the transmission is to change the speed ratio between the engine and the wheels of an automobile.

- The transmission uses a range of gears -- from low to high -- to make more effective use of the engine's torque as driving conditions change. The gears can be engaged manually or automatically.
able to accelerate well from a complete stop

Gear 1

able to climb

top speed is limited

very slow acceleration when starting from a complete stop

Gear 3

wouldn't be able to climb hill

top speed is relatively high

A five-speed transmission applies one of five different gear ratios to the input shaft to produce a different rpm value at the output shaft. Here are some typical gear ratios:

<table>
<thead>
<tr>
<th>Gear</th>
<th>Ratio</th>
<th>RPM at Transmission Output Shaft with Engine at 3,000 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2.315:1</td>
<td>1,295</td>
</tr>
<tr>
<td>2nd</td>
<td>1.568:1</td>
<td>1,913</td>
</tr>
<tr>
<td>3rd</td>
<td>1.195:1</td>
<td>2,510</td>
</tr>
<tr>
<td>4th</td>
<td>1.000:1</td>
<td>3,000</td>
</tr>
<tr>
<td>5th</td>
<td>0.915:1</td>
<td>3,278</td>
</tr>
</tbody>
</table>
Problems in manual & automatic transmission

Engine Torque > Drive Shaft Torque
Benefits of CVT

- Provide engine torque in optimum condition (road loads / drive shaft torque)
- No shift clonk
- Transmission ratio can be adjusted continuously
- Improved fuel efficiency
- Better acceleration
- Eliminates gear hunting especially when going up a hill
Behavior of CVT

MT

CVT

vehicle velocity [km/h]
g0066
g0101
g0097
g0118
g0105
g0111
g0114
g0032
g0111
g0102
g0032
g0067
g0086
g0084

engine speed [RPM]

www.cvt.com.sapo.pt

engine speed [RPM]
CVT Design

- Pulley based CVT
- Toroidal CVT
- Hydrostatic CVT
Pulley based CVT
Belt Design

- Pulleys
- V Belt

Steel bands

Thin, high-strength metal
Toroidal CVT
CVT Control
Mathematical Model of CVT

Fig. 1. Simplified model of transmission system

From the figure we can obtain the dynamic equations as follows:

\[ I_e \dot{\omega}_e + B_e \omega_e = T_e - T_{cl} \]  \hspace{1cm} (1)

\[ I_s \dot{\omega}_s + B_s \omega_s = T_{cl} - T_{in} \]  \hspace{1cm} (2)

\[ I_q \dot{\omega}_q + B_q \omega_q = i \eta T_{in} - T_r \]  \hspace{1cm} (3)

In which, \( I_e \) is the rotary inertia of engine; \( I_s \) is the rotary inertia of the active pulley of CVT; \( I_q \) is the rotary inertia of the passive pulley of CVT; \( B_e, B_s \) and \( B_q \) represent the equivalent damping coefficient of each axis respectively; \( i \) is the speed ratio of CVT and \( \eta \) is the transmission efficiency of CVT, \( T_r \) is the equivalent resistance torque of car weight and load converted to the output axis of CVT.
\[ T_r = \frac{r}{i_0 i_z} F_r = \frac{r}{i_0 i_z} \left[ G f \cos \theta + \frac{1}{2} C_D A \rho u^2 + G \sin \theta + (m + \frac{\sum I_w}{r^2}) \frac{du}{dt} \right] \]

When the clutch is in unlocked condition, in terms of above equations, the integrated dynamic equation is obtained.

\[
\begin{aligned}
& I_s \dot{\omega}_s + B_s \omega_s = T_e - T_{cl} \\
& \left[ I_s + \frac{I_g}{\eta^2} + \frac{(m + \frac{\sum I_w}{r^2})}{\eta^2} \right] \frac{r}{i_0 i_z} \dot{\omega}_s + \left[ B_s - \frac{I_g}{\eta^3} \right] \frac{d}{dt} \omega_s + \frac{C_D A \rho}{2 \eta^3} \frac{r}{i_0 i_z} \omega_s^2 = T_{cl} - \frac{r}{\eta i_0 i_z} (G f \cos \theta + G \sin \theta)
\end{aligned}
\]

On the other hand, when the clutch is in locked condition, the integrated dynamic equation is as follows

\[
\begin{aligned}
& I_s + I_e + \frac{I_g}{\eta^2} + \frac{(m + \frac{\sum I_w}{r^2})}{\eta^2} \frac{r}{i_0 i_z} \dot{\omega}_s + \frac{B_s}{\eta^3} \frac{d}{dt} \omega_s + \frac{C_D A \rho}{2 \eta^3} \frac{r}{i_0 i_z} \omega_s^2 = \\
& T_e - \frac{r}{\eta i_0 i_z} (G f \cos \theta + G \sin \theta)
\end{aligned}
\]