Continuously Variable Transmission

The continuously variable transmission (CVT) is a transmission in which the ratio of the rotational speeds of two shafts, as the input shaft and output shaft of a vehicle or other machine, can be varied continuously within a given range, providing an infinite number of possible ratios.

A CVT need not be automatic, nor include zero or reverse output. Such features may be adapted to CVTs in certain specific applications. Other mechanical transmissions only allow a few different discrete gear ratios to be selected, but the continuously variable transmission essentially has an infinite number of ratios available within a finite range, so it enables the relationship between the speed of a vehicle, engine, and the driven speed of the wheels to be selected within a continuous range. This can provide better fuel economy than other transmissions by enabling the engine to run at its most efficient speeds within a narrow range.

About CVT
How CVTs work and how they improve performance, etc....

- The purpose of CVTs-To vary the transmission ratio continuously.

- Working of CVT depends on the type of CVT:
  o Friction CVTs vary the radius of the contact point between two rotating objects, thus the tangential velocity;

  o Hydrostatic CVTs vary the fluid flow with variable displacement pumps into hydrostatic motors

  o Ratcheting CVTs vary the stroke of a reciprocating motion, which is connected to a free-wheel, resulting unidirectional rotation.

- CVT improves efficiency by allowing the engine to operate always in it's optimum R.P.M., whatever the vehicle's speed.

- What are the benefits of operating in the optimum R.P.M.?
  o Lower consumption;
  o Less greenhouse gas emissions;
  o Better performance;
• CVT is the ideal transmission, so why are there so few CVT cars?
  The existing inventions are based on
  o Friction,
  o hydrostatic,
  o Ratcheting which are all mechanical systems with inherent limitations, (compared to traditional transmissions).

• How to extract the full CVT potential?
• A conceptual innovation is the only way out. Although, research continues improving the friction CVTs and ratcheting CVTs, these efforts are accomplished by expensive high tech materials and precision manufacturing. This is to overcome the inherent limitations of these concepts (friction and ratcheting).

TYPES OF CVTs

1. Frictional Type CVTS
The most common type of CVT is the frictional type, in which two bodies are brought into contact at points of varying distance from their axes of rotation, and allowing friction to transfer motion from one body to the other. Sometimes there is a third intermediary body, usually a wheel or belt.

The simplest CVT seems to be the "disk and wheel" design, in which a wheel rides upon the surface of a rotating disk; the wheel may be slid along its splined axle to contact the disk at different distances from its center. The speed ratio of such a design is simply the radius of the wheel divided by the distance from the contact point to the center of the disk.

Friction plays an important part in frictional CVT designs - the maximum torque transmissible by such a design is:

\[ T_{\text{max}} = C_f \times F_N \times R_o \]

where \( T_o \) is the torque output, \( C_f \) is the coefficient of friction between the wheel and the disk, \( F_N \) is the force pushing the wheel into the disk (normal force), and \( R_o \) is the radius of the output wheel or disk. The coefficient of friction depends on the materials used; rubber on steel is typically around 0.8 to 0.9.

**Power is lost in two ways:**

- Deformation of the components;
- Differential slip.

Deformation of the components, the larger factor of the two, is caused by high normal forces, and can be minimized by using very hard materials that do not deform much, and materials with a very high coefficient of friction. Differential slip is caused by a large contact area between the rotating components; in this example, the "footprint" of the wheel riding on the disk. The edge of the footprint closest to the axis of rotation of the disk will roll along a smaller radius than the edge furthest from the axis of rotation, causing further distortion of the wheel and the edges of the footprint to slip. Differential slip is minimized by using a hard wheel that produces a small contact area.

Very similar to the "disk and wheel" is the "cone and wheel" design, in which the disk is replaced by a cone. There is little advantage to
using a cone instead of a flat disk, except to decrease the differential slip of the contact surface by minimizing the difference in the radius traveled by the inner and outer edges of the contact area. Other designs have used different shapes, but the principle remains the same.

More advanced designs used three bodies instead of two. There are two advantages to using three bodies: an increase in speed ratio range; and a simpler design. However, the range of speed ratios usually crosses unity - for example, it might range from 1:5 to 5:1 - making necessary a secondary gear sets, often a planetary set. Almost all such designs are based on toroidal contact surfaces, an exception being the "dual cone" design, which only affords the former advantage.
Toroidal CVT

The simplest toroidal CVT involves two coaxial disks bearing annular grooves of a semi-circular cross section on their facing surfaces. The spacing of the disks is such that the centers of the cross sections coincide. Two or more (in patent-speak, "a plurality of") idler wheels, of a radius equal to the radius of the cross sections of the grooves, are placed between the disks such that their axes are perpendicular to, and cross, the axes of the disks.

In the image, the speed ratio is varied by rotating the wheels in opposite directions about the vertical axis (dashed arrows). When the wheels are in contact with the drive disk near the center, they must perforce contact the driven disk near the rim, resulting in a reduction in speed and an increase in torque. When they touch the drive disk near the rim, the opposite occurs. This type of transmission has the advantage that the wheels are not required to slide on a splined shaft, resulting in a simpler, stronger design.

Just as the disk CVT evolved into the cone CVT, the toroidal CVT has evolved toward a cone-shape as well. The result is a much more compact transmission. This type is peculiar in that the speed ratio may be controlled by directly rotating the wheels, or by moving them slightly up or down, causing them to rotate and change the speed ratio on their own.
Some more detail about Toroidal CVT

Another version of the CVT - the toroidal CVT system -- replaces the belts and pulleys with **discs** and **power rollers**.

![Diagram of Toroidal CVT](image)

Although such a system seems drastically different, all of the components are analogous to a belt-and-pulley system and lead to the same results -- a continuously variable transmission. Here's how it works:

- One disc connects to the engine. This is equivalent to the driving pulley.
- Another disc connects to the drive shaft. This is equivalent to the driven pulley.
- Rollers, or wheels, located between the discs act like the belt, transmitting power from one disc to the other.

The wheels can rotate along two axes. They spin around the horizontal axis and tilt in or out around the vertical axis, which allows the wheels to touch the discs in different areas. When the wheels are in contact with the driving disc near the center, they must contact the driven disc near the rim, resulting in a reduction in speed and an increase in torque (i.e., low gear). When the wheels touch the driving disc near the rim, they must contact the driven disc near the center, resulting in an increase in speed and a decrease in torque (i.e., overdrive gear). A simple tilt of the wheels, then, incrementally changes the gear ratio, providing for smooth, nearly instantaneous ratio changes.
Variable diameter pulleys type CVT

Variable diameter pulleys are a variation in the theme. Two 20° cones face each other, with a v-belt riding between them. The distance from the center that the v-belt contacts the cones is determined by the distance between them; the further apart they are, the lower the belt rides and the smaller the pitch radius. The wider the belt is, the larger the range of available radii, so the usual 4L/A series belt is not often used in this way. Often special belts, or even chains with special contact pads on the links, are used. Variable diameter pulleys must always come in pairs, with one increasing in radius as the other decreases, to keep the belt tight. Usually one is driven with a cam or lever, while the other is simply kept tight by a spring. Variable diameter pulleys have been used in a myriad of applications, like

- power tools
- Snowmobiles,
- Automobiles.

The variable-diameter pulleys are the heart of a CVT. Each pulley is made of two 20-degree cones facing each other. A belt rides in the groove between the two cones. V-belts are preferred if the belt is made of rubber. V-belts get their name from the fact that the belts
bear a V-shaped cross section, which increases the frictional grip of the belt. When the two cones of the pulley are far apart (when the diameter increases), the belt rides lower in the groove, and the radius of the belt loop going around the pulley gets smaller. When the cones are close together (when the diameter decreases), the belt rides higher in the groove, and the radius of the belt loop going around the pulley gets larger. CVTs may use hydraulic pressure, centrifugal force or spring tension to create the force necessary to adjust the pulley halves.

Variable-diameter pulleys must always come in pairs. One of the pulleys, known as the drive pulley (or driving pulley), is connected to the crankshaft of the engine. The driving pulley is also called the input pulley because it’s where the energy from the engine enters the transmission. The second pulley is called the driven pulley because the first pulley is turning it. As an output pulley, the driven pulley transfers energy to the driveshaft.

The distance between the centers of the pulleys to where the belt makes contact in the groove is known as the pitch radius. When the pulleys are far apart, the belt rides lower and the pitch radius decreases. When the pulleys are close together, the belt rides higher and the pitch radius increases. The ratio of
the pitch radius on the driving pulley to the pitch radius on the driven pulley determines the gear

Variable diameter friction gears are very similar, only with the belt replaced by a wheel with friction surfaces along the sides of its circumference. The two wheels are moved together or apart to control the speed ratio, with the proper distance between the cones being maintained by a spring.

2. Electrical Type

It could easily be argued that a generator powering a motor through some kind of electronic speed control would constitute a continuously variable transmission. Electrical transmissions have the advantage of great flexibility in layout, as the generator can be located at any distance or orientation with the motor. Furthermore, any excess power generated can be stored in batteries, and drawn upon when high loads are experienced. However, they are heavy and inefficient. A typical generator or motor is only 75% to 80% efficient, so compounding two results in an efficiency of only 56% to 64%. This limits their use to situations where other types of transmissions cannot be used.

Diesel locomotives and some ships use such drive trains, and more recently, "hybrid" gas-electric cars.

3. Hydraulic Type

A hydraulic CVT is a hydraulic pump driving a hydraulic motor, at least one of which has a variable displacement. If, for example, the pump has a variable displacement, the increasing the displacement will obviously increase the speed of the motor. If the motor has a variable displacement, then the situation is reversed; increasing the displacement will decrease the speed at which it turns, as the volume produced by the pump remains constant. Decreasing the displacement of the motor will likewise increase its speed.

This kind of transmission is used in the Honda Rubicon ATV. It consists of a hydraulic swash plate pump driving a swash plate hydraulic motor. The motor is variable displacement, achieved by controlling the angle of the swash plate.
"Hydrostatic" CVTs

Principle: Hydrostatic CVTs convert rotational motion into fluid flow (hydrostatic pump), and then back to rotational motion (hydrostatic motor).

In some cases the fluid flow is continuously varied by variable displacement pump. There are other cases where the variable displacement unit is the hydrostatic motor, or both.
Some examples of "Hydrostatic" CVTs:

Hydrostatic CVTs for Tractors:

Hydrostatic CVTs for Motorcycles:
Hydrostatic CVTs for Bikes:
4. "Ratcheting" CVTs or "Crank-CVT" or "Variable-Stroke CVT"

Principle:

These CVTs convert uniform motion to reciprocating motion, and then rectify it back to an "almost" uniform motion.

Firstly, there is a mechanism that produces reciprocating motion from rotational input. This mechanism allows adjustable reciprocating stroke.

Secondly, the reciprocating motion is rectified by a mechanism such as a one-way-clutch (or free-wheel). Thus, the reciprocating motion is rectified to a unidirectional rotational output.

It is possible to adjust the speed of this rotational output simply by adjusting the reciprocating stroke.

To obtain a smoother output motion, several out-of-phase cranks are used:
Some examples of "Ratcheting" CVTs:

Bike-CVTs (reciprocating input -> rotational output)
What are the steps to select a CVT?

1. Determination of the "highest ratio"
Usually the "highest ratio" is selected so that it will allow the achievement of the maximum possible speed. Nevertheless, a higher ratio is also used to benefit highway fuel economy. (But it would not achieve the top speed.) Thus, we need to know the vehicle's maximum speed, using the given power.

1.1. Available power?
Considering that the engine power is $P_e = 99$ [hp], and the transmission efficiency (incl. rolling resistance) is $\text{Eff} = 70\%$, and the available power ($P_t$) of the transmission will be:

$$P_t = P_e \times \text{Eff} = 69.3 \text{[hp]} = 50970.0 \text{[w]}.$$ 

1.2. Thrust force?
At a speed $v$ (m/s), the Thrust force will be $T_f = \frac{P_t}{v} = 50970.0/v \text{[N]}$ 

1.3. Drag force?
To determine the maximum speed we must also calculate the Drag force, $D_f$. The

$$D_f = C_d \times \frac{1}{2} \times r \times v^2 \times A$$

where:

- $C_d$: drag force coefficient: 0.4 
- $r$: air density (=1.2 [kg/m³]) 
- $v$: vehicle velocity (m/s)
A: - Vehicle's projected frontal area: 1.9 [m²]

1.4. Maximum speed?
Therefore the maximum velocity will be calculated by equating the Thrust force to the Drag force ($T_f = D_f$), and solving for the velocity: 
$$v^3 = \frac{P_t}{(C_d \times \frac{1}{2} \times r \times A)}$$

Thus
$$v_{\text{max}} = 48.17 \text{[m/s]} = 173.4 \text{[km/h]} = 107.7 \text{[mph]}$$

1.5. Highest ratio?
Considering that the maximum power is at 5000rpm ($\text{rpm}.P$), the wheel diameter is 24.9 [inch] ($\text{w.diam}$, use the calculator at the right → ),
and the differential ratio is 3.8:1,
the highest ratio ($\text{high.ratio}$) will be calculated by the equation:
$$v_{\text{max}} = (\text{rpm}.P \times 2 \times 3.1416/60) \times ((\text{w.diam} \times 0.0254)/2) / (\text{high.ratio} \times \text{differential})$$

Thus
high.ratio = \( (\text{rpm.P} \times 2 \times 3.1416/60) \times ((\text{w.diam} \times 0.0254)/2) / \) \( (\text{v.max} \times \text{differential}) \) 
and therefore the high.ratio 0.90455
Note: this “highest ratio” value was selected in order to optimize the maximum speed.

2. Determination of the lowest ratio

2.1. Force due to the slope?
Consider that the car must be able to start moving uphill, fully loaded. The vehicle's mass is 950[kg] and the maximum load is 700[kg] (incl. passengers). The slope inclination, (percent.incl), is 10[%] and the safety factor is 2.0. The force due to the slope will be:
\( F\text{.slope} = (\text{mass} + \text{load}) \times 9.81 \times (\text{percent.incl}/100) \times \text{safety} / \text{Eff} = 4624.71[N]; \) (note: Eff is the transmission efficiency).

2.2. Available tangential force in the tyres:
The maximum engine torque is 170[Nm]. However when starting to move the clutch slip results in an efficiency of 60% (clutch.eff).
So the tangential force in the tyres will be:
\( F\text{.tyres} = \text{torque} \times \text{clutch.eff} \times \text{low.ratio} \times \text{differential} / ((\text{w.diam} \times 0.0254)/2) \)
2.3. lowest ratio?
Equating \( F_{\text{slope}} = F_{\text{tyres}} \) and isolating \( \text{low.ratio} \) results:
\[
\text{low.ratio} = F_{\text{slope}} \times \left( \frac{w_{\text{diam}} \times 0.0254}{2} \right) / (\text{torque} \times \text{clutch.eff} \times \text{differential})
\]
thus
\[
\text{low.ratio} = 3.77315:1 \quad \text{So, at this point we already know the required “lowest ratio” and “highest ratio”}.
\]

3. Addition of an external fixed ratio to obtain symmetric ratios:
The previous calculations resulted in:
\[
\text{low.ratio} = 3.77315 \quad \text{high.ratio} = 0.90455
\]
However a V-Belt CVT usually generates (almost*) symmetric extreme ratios:
\[
[ \text{low.ratio} \times \text{cf} = 1 / \text{high.ratio} ]
\]
Because both pulleys move apart by equal amounts (alternatively).
*Note: \( \text{cf} = 0.91 \) is a correction factor. Lower \( \text{cf} \) values are used to lower the whole ratio span within the CVT (\( \text{cf} = 0.9 \) to 0.99) which is beneficial.
Therefore, we must add a fixed reduction after the V-Belt CVT.
This way the V-Belt CVT will be able to have a (almost) symmetric ratio span. The fixed reduction ensures that the final ratio span will be exactly from \( \text{low.ratio} \) to \( \text{high.ratio} \).
Therefore, we must add (in series) a final (fixed) reduction with a ratio of:
\[
k = \sqrt{\text{low.ratio} \times \text{high.ratio} \times \text{cf}}
\]
thus \( k = 1.76234 \),
Now we must calculate the new CVT’s high and low ratios. These will result from dividing each of initial \( \text{low.ratio} \) and \( \text{high.ratio} \) by \( k \).

\textbf{Conclusion:}
in this case the CVT’s symmetric ratios will be \( 2.1408 = \text{s.l.ratio} \),
And \( 0.51326 = \text{s.h.ratio} \).
4. CVT dimensions:

4.1. Pulley:
Considering that the smaller diameter (D1) is 50 [mm] and that the bigger is (D2) will be so that \( \frac{D1}{D2} = \text{s.h.ratio} \).
Thus \( D2 = \frac{D1}{\text{s.h.ratio}} = 97.4149 \text{[mm]} \).
Specify the pulley groove angle: \( \beta = 30^\circ \)

4.2. Pulley groove angle & Belt:
Specify the pulley groove angle: \( \beta = 30^\circ \)
Knowing that the pulleys centre-to-centre distance is \( a = 300 \text{[mm]} \)
(note: it must be greater than 97.4149[mm]),
the belt length will be \( 2 \times a + \frac{\pi}{2} \times (D2 + D1) + \frac{(D2 - D1) \times (D2 - D1)}{4 \times a} \).
Thus the belt length \( 833.432 \text{[mm]} \).
5. Velocities: (considering the maximum power regime)

5.1. Velocities in the lowest ratio:
Rotational speed driver pulley = 5000[rpm]; \( n_1 \);
Rotational speed driven pulley 2335.37[rpm]; \( n_2 = n_1 / s.l.ratio \);
Belt speed = \( 13.0899 \text{[m/s]} \); \( (n_1 \times 2 \times \pi / 60) \times (D_1/2) \)

\[ n_1 \]
\[ n_2 \]

5.2. Velocities in the highest ratio:
Rotational speed driver pulley = 5000[rpm]; \( n_1 \);
Rotational speed driven pulley 9741.48[rpm]; \( n_2 = n_1 / s.h.ratio \);
Belt speed = \( 25.5031 \text{[m/s]} \);

\[ n_1 \]
\[ n_2 \]

6. Forces:

6.1. Friction coefficient:
Consider the coefficient of friction is \( \mu = 0.3 \).
Therefore, the effective friction coefficient will be calculated by
\( \mu_e = \mu / \sin(\beta/2) = 1.158 \)

6.2. Belt tensions in the lowest ratio:
The lowest ratio is 2.14098.
In the following, we will use \( D_1 = 50 \text{[mm]} \) for the driver pulley,
and \( D_2 = 97.4149 \text{[mm]} \) for the driven pulley.
The smallest belt wrap angle is calculated by 
\[ 2 \times \text{acos} \left( \frac{\text{D2} - \text{D1}}{2 \times \text{a}} \right) \], thus \( \text{alpha} = 170.934^\circ \);

The ratio of the belt forces will be \( \exp (\mu \times \text{alpha}) \), so \( \text{T12} = 31.7555\); 
Belt tension load \( \text{T1} \) will be \( \frac{\text{Pe}}{\text{Belt speed}} / (1 - 1/\text{T12}) = 5743.47[N] \); 
(Note: Pe is the engine power). 
Belt tension load \( \text{T2} \) will be \( \frac{\text{T1}}{\text{T12}} = 180.865[N] \);

And the shaft load can be calculated by: 
\[ (\text{shaft load})^2 = \text{T1} \times \text{T1} + \text{T2} \times \text{T2} - 2 \times \text{T1} \times \text{T2} \times \cos(\text{alpha}) \]; 
Thus, \( \text{shaft load} = 5922.14[N] \); 
Axial \( \text{clamping force} = (\frac{\text{Pe}}{\text{Belt speed}}) / \mu \times e = 4799.03[N] \)

6.3. Belt tensions in the highest ratio: 
The highest ratio is 0.5132 
Now the driver pulley is \( \text{D1} = 97.4149[\text{mm}] \), and the driven pulley is \( \text{D2} = 50[\text{mm}] \).
The smallest belt wrap angle is \( \alpha = 170.934^\circ \);

The ratio of the belt forces will be \( T_{12} = 31.755 \);  
Belt tension load \( T_1 = 2947.94 \) [N];  
Belt tension load \( T_2 = 92.8325 \) [N];
And the \textit{shaft.load} = 3039.65[N]; Axial \textit{clamping.force} = ( Pe/Belt\_speed )/ \textit{mu.e} = 2463.19[N].
How much does CVT benefit?

It is advantageous to use a CVT, instead of a manual transmission. This is mainly because the engine will operate always on the optimum regimes and throttle-positions, adapted to the varying road conditions and power demands.

But is this advantage enough to overcome the inherent limitations and dissipations of the common friction CVTs?

In order to quantify the advantage of using a CVT, we will ignore the inherent limitations and dissipations of the common friction CVTs. This will be a simplified approach.

To compare performances, we calculate how much time [seconds] is necessary to accelerate a car from rest to 100 km/h using Manual Transmission (MT). Then we will calculate it with the same car, but using a CVT. In both cases, we will neglect all energy losses such as clutch transitions, aerodynamics, etc, and we consider the road is horizontal.

1st case: Manual Transmission (MT):

Consider a utility vehicle:

<table>
<thead>
<tr>
<th>mass: M=1250 kg;</th>
<th>wer: power=75 pm</th>
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Note: 'mass' includes passengers and luggage (350kg)

The transmission ratios (output speed/input speed) include the differential ratio:

\[
i_1 = 0.066 \quad i_2 = 0.095 \quad i_3 = 0.14 \quad i_4 = 0.19 \quad i_5 = 0.28
\]

Example: to calculate the car speed on first gear at 5700 rpm:

\[V = 5700 \text{rpm} \times i_1 \times \text{wheel_radius} \times k_1 = 43 \text{ km/h} \quad \{\text{Eq.1}\}\]

Note: \(k_1\) is units conversion factor,

\[k_1 = \frac{2\pi\text{rad/1rot}}{(60\text{s/1min})}(1\text{km/1000m})/(1\text{h/3600s}) = 0.3768\text{min*km/m*h}\]
We are considering a real case: it's a small vehicle sold in Europe in 1991. This is the engine's power/torque diagram. To simplify calculations, we will consider the blue line as the torque values. The torque value used is the torque corresponding to the maximum power (@5700rpm).

According to the technical specifications, this car takes 12.1s to accelerate from rest to 100 km/h. If we include luggage and passengers, the value should rise to about 15.5s.

Anyway, we will have to calculate this MT case theoretically in order to compare with the corresponding theoretical calculations for the CVT case.

During each gear, the torque will be almost constant, and so will be the car's acceleration. Force=Power/Velocity. Also, Acceleration=Force/Mass. Thus,

\[ \text{Acceleration} = \text{Power} / (\text{Velocity} \times \text{Mass}) . \]

Consider the ultimate car speed during the 1st gear that is 43km/h.
(@5700rpm). The power is 55kW, so the constant acceleration value can be calculated by:

$$\text{Acceleration}_{1st} = \frac{55\text{kW}}{43\text{km/h} \times \text{Mass}} \times k_2 = \text{Acc}_{1st} = 3.7 \text{ m/s}^2$$

Note: $k_2$ is units conversion factor,

$$k_2 = \frac{1\text{km}}{1000\text{m}} \times \frac{1\text{h}}{3600\text{s}} = 3.6\text{km/s/m.h}$$

Similarly for the other gears: $\text{Acc}_{2st} = 2.6 \text{ m/s}^2$ ; $\text{Acc}_{3st} = 1.8 \text{ m/s}^2$ ; $\text{Acc}_{4st} = 1.3 \text{ m/s}^2$ .

The 5th gear acceleration isn't requires because 100km/h are attained in 4th gear.

The time required to attain 100km/h is the sum of the time spent on each gear.
The uniformly accelerated movement has the equation:

$$\text{Final}_\text{Velocity} = \text{Initial}_\text{Velocity} + \text{Acceleration} \times \text{Time} \quad \Rightarrow \quad \text{Time} = \frac{(\text{Final}_\text{Velocity} - \text{Initial}_\text{Velocity})}{\text{Acceleration}}$$

Let's calculate the time during the 1st gear:

$$\text{Time}_{1st} = \frac{(43\text{km/h} - 0\text{Km/h})}{(\text{Acc}_1 \times k_2)} = 3.2\text{s}$$

Similarly for the other gears and summing up, we conclude that the theoretical required time to accelerate from rest to 100km/h, using a manual transmission (MT), will be:

**MT\_Time = 11.9s**

Note: The difference between the real value (15.5s) and the theoretical value (11.9) may be easily understood considering about 3.5s for gear shifting.

**2nd case: Continuously Variable Transmission (CVT):**

Now we will calculate the required time to accelerate from rest to 100km/h, using a Continuously Variable Transmission (CVT). To simplify calculations, we will consider the IVT case, because it allows continuous ratio variation from rest.
To maximize acceleration, power must be kept on its greatest value.

While accelerating, Force = Power / Velocity,
According to Newton’s Law, Force = Mass * Acceleration,
Equating, becomes, Power / Velocity = Mass * Acceleration,
Acceleration is the derivate of Velocity in order to time: \( \frac{dv}{dt} \).
Thus, separating variables:
Velocity * Mass * \( \frac{dv}{dt} \) / Power = 1,
Integrating \( \int \) this differential equation on both sides, becomes,
\( \int ( \text{Velocity} \times \text{Mass} / \text{Power} ) \, dv = \int (1) \, dt \)
Considering null constants, \( (\text{Velocity}^2 / 2) \times (\text{Mass} / \text{Power}) = \text{Time} \)
Substituting Velocity=100km/h, M=1250kg, Power=75cV, results on:
**CVT Time = 8.8s**

**Conclusion:**

The Continuously Variable Transmission (CVT) is **35% more performant** than the Manual Transmission (MT). With same car and engine, the CVT takes only **75% of the time to accelerate to 100km/h**, compared to the MT.
**Conclusion means that:**

- Although the known CVTs (ex: "V"belt, Toroidal) have greater inherent dissipations than MT, they may be still advantageous.

- To take full advantage of the whole 35% improvement of CVT, it would be necessary to invent something as a "Geared CVT", (without the unavoidable limitations of friction CVTs).

If it is difficult to eliminate significantly the energy losses of some friction drives, then these CVT will hardly improve performances up to 35%. Power split and similar techniques may help here

**CVTs boosting performance of racing cars**

The most remarkable practical proof of the CVT performance was the CVT use in the 800cV Formula One Canon-Williams-Renault, in 1993. Without so much development as the MT version, the experimental CVT Formula One was **1 second faster** per lap

**Advantages of CVTs**

1. Constant, stepless acceleration from a complete stop to cruising speed which Eliminates "shift shock" -- makes for a smoother ride

2. Works to keep the car in its optimum power range regardless of how fast the car is traveling which Improves fuel efficiency

3. Responds better to changing conditions, such as changes in throttle and speed which Eliminates gear hunting as a car decelerates, especially going up a hill
4. Less power loss in a CVT than a typical automatic transmission gives Better acceleration

5. Better control of a gasoline engine's speed range which gives Better control over emissions

6. Can incorporate automated versions of mechanical clutches which Replaces inefficient fluid torque converters

A CVT Test Drive

Cars with CVTs have been common in Europe for years. But it's taken a while for the technology to gain a foothold in the United States. The first production automobile to offer a CVT in the United States was the Subaru Justy.

Sold between 1989 and 1993, the Justy never attracted the attention of American drivers. So what's different about newer CVT-based cars -- cars like the Saturn Vue, the Audi A4 and A6, the Nissan Murano and the Honda Insight? The best way to answer that question is to take one of these cars for a "test drive." The animation below, which compares the acceleration of a car with a CVT to one without, gives you a good feel for the experience. When you step on the gas pedal of a car with a continuously variable transmission, you notice the difference immediately. The engine revs up toward the rpms at which it produces the most power, and then it stays there. But the car doesn't react immediately. Then, a moment later, the transmission kicks in, accelerating the car slowly, steadily and without any shifts. In theory, a car
with a CVT should reach 60 mph (100 km/hr) 25-percent faster than the same car with the same engine and a manual transmission. That's because the CVT converts every point on the engine's operating curve to a corresponding point on its own operating curve.

CVTs are equally efficient on hills. There is no "gear hunting," because the CVT cycles steplessly down to a gear ratio appropriate for the driving conditions. A conventional automatic transmission shifts back and forth trying to find the right gear, which is far less efficient.

With all of their advantages, CVTs do have some shortcomings. Traditionally, belt-drive CVTs were limited in the amount of torque they could handle and were larger and heavier than their automatic and manual counterparts. Technological advances have put CVTs in the realm of their competition -- the Nissan Murano's CVT can handle its 3.5-liter, 245-horsepower V6 engine -- but first impressions are hard to overcome.

**A Case study of Audi cars having CVTs**

![Audi multitronic CVT showing the variator with link-plate chain](image1)

1st is the Audi multitronic CVT showing the variator with link-plate chain & 2nd is the General view of Audi multitronic CVT.

In 1490, Leonardo da Vinci made a sketch that indicated the potential of the stepless continuously variable transmission (CVT). Leonardo, it seems, took the invention of the automobile itself as mundane and obvious: He just wanted to get down to details. He reckoned two pedals would be better than three and that conventional gears were already passe. However, he has had a long wait. CVTs may be great in theory but the fact is they have a questionable image and have made, until recently, relatively little impact on the automotive scene.
Now, Audi has revealed that it has developed a new CVT it believes overcomes the drawbacks of earlier systems and will, at last, make the principle generally acceptable. It adds that its CVT, which it calls multitronic, when installed in an A6 sedan or wagon (Avant) not only offers markedly better fuel consumption than a regular automatic but gives marginally improved acceleration to 100 km/h (62 mph) compared to a five-speed manual. And Audi feels it can offer the system at only slightly higher cost than its current conventional automatic. AEI went to Germany to find out more.

In Europe, Daf in The Netherlands produced a CVT for a car in 1958. This was developed and improved over the years. Basically it was a simple (some would say crude) rubber band and cone system. The attractions of CVT are (in theory) many and varied, including seamless power delivery, the ability to allow the engine to rev almost immediately to deliver maximum torque, and a wide spread of ratios. However, the Daf CVT had something of an image problem. Because it was simple to use with just a stick shift for selecting forward or reverse and fitted to a low-powered car (the original production Daf had a 0.6-L engine) it was popular with older people. Later, the system was taken up by various manufacturers but at a time when cars were becoming quieter and more refined. The CVT's trait of going to high revs on wide throttle openings with subsequently increased interior noise levels met with customer resistance. It was also decided that the system should have low speed "creep" similar to that of a regular automatic for low-speed maneuvering or when driving in very slow city traffic. But this created a jerky response. Its performance was improved as more advanced electronics were developed, but the electronics actually became a limiting factor. There was also a problem with regard to the maximum torque that could be handled by a CVT even when the rubber belt was replaced by a steel thrust belt.

Audi's research and development engineers watched all this with caution and it has been almost 20 years since its first tentative CVT work started, and only now it feels that it has overcome the system's minus points and enhanced its pluses. To demonstrate it, Audi invited AEI to sample its multitronic system fitted to a 2.8-L A6, over a mixed route of regular roads and autobahn. It is unlike other CVTs experienced by this journalist. Audi states that multitronic finally overcomes all the drawbacks of the stepless principle, and that the multitronic is the first transmission of its kind not to pay the high price of poorer dynamism and economy for the added convenience it brings. A key element of the Audi design is a variator that Audi explains adopts a new transmission element called a link-plate chain made
entirely from steel, said to be almost as flexible as a V-belt (it has been tested "over a number of years"), to handle the high forces and torque levels of the A6's engine, which has a peak torque of 280 N•m (207 lb•ft). The variator allows a spread of ratios equating to a six-speed system: due to its high maximum torque ratio, the variator facilitates acceleration from rest and renders a hydraulic torque converter unnecessary. Audi has opted instead to use an oil-cooled multi-plate clutch which it said implements a variety of starting strategies which respond to driver preference via sensors linked to the accelerator pedal. The system allows sport or economy mode driving. The multi-plate clutch also provides constant creep behavior. By optimizing the hydraulics, the transmission engineers have ensured that the adjustment processes take place dynamically and without any trailing effects. The "rubber band effect" or "slipping clutch syndrome," which have been a common source of criticism on conventional CVTs, are essentially banished.

The variator uses a novel dual-piston system and oil flow is separated into high pressure and cooling circuits. Pump output of the hydraulic system is said to be lower than that of a conventional transmission, which aids in efficiency and road performance. The rubber band effect is avoided by electronically controlled speed tracking, producing, says Audi, dynamic driving properties in conjunction with a reassuringly familiar pattern of sound — in other words, the engine does not rev
with manic insistence as the car's speed "catches up." Multitronic also has a "manual" mode with six fixed transmission stages, working in a similar way to the manual one-touch sequential element of a conventional automatic transmission. Audi claims that the multitronic A6 accelerates from 0-100 km/h (0-62 mph) 1.3 s quicker than a geared automatic transmission and is 0.1 s quicker over the same speed than an equivalent model with "optimum" use of a five speed manual gearbox. Gasoline consumption measured to EU standards shows a 0.9-L (0.25-gal) savings over 100 km (62 mi) less than an automatic and 0.2 L (0.04 gal) less than a manual. Audi claims it to be the first automatic transmission to achieve lower fuel consumption and better performance than an otherwise identical model with a manual five-speed gearbox. Audi opted to use magnesium for the gearbox housing and claims the multitronic as the first automatic transmission to use the material. "This factor alone brought about a weight reduction of approximately 7 kg (15.4 lb)," says Reinhard Gesenhaus, Audi's Manager of Transmission Engineering, who discussed some of the other key elements of the multitronic system. "We used an oil cooled drive-off clutch to replace the torque converter usually found in automatic transmissions. An input side step-down gear matches the torque to the variator and provides a suitable overall ratio. The variator with link-type chain provides a continuously variable ratio according to torque and engine speed. Output to the front wheels is via an integral front axle differential. The hydraulic control unit with integrated pump and local electronic system is installed at the rear of the transmission."