CVT Basics

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Goal: This guide aims to provide a brief introduction on the most important aspects of tuning a CVT system. The unit used by Olin Baja as of the 2016 competition season is the Gaged GX-9 System with a reversed helix but this guide will largely be generalized.

CVT System: A Continuously Variable Transmission consists of 3 main parts:

1. The primary clutch (driving)
2. The secondary clutch (driven)
3. The belt

Additionally, there are 3 more crucial parts of the assembly:

a. Weights (located in the primary clutch)
b. Helix (located in secondary clutch)
c. Contra spring (located in secondary clutch)

Note: There is also a spring located in the primary clutch though this team has not historically adjusted and so it will not be addressed in this paper for simplicity.

These are usually the most adjusted parts within the assembly. The CVT's function depends most heavily on the input from the engine and theoretically should "shift" continuously through infinite ratios between the upper and lower limit of the system.

The CVT will start in the initial orientation (Fig.1) such that the radius of the belt from one end (primary clutch) to the other end (secondary clutch) will be in a "low to high" orientation resulting in a high gear reduction simulating a "low gear" as seen in more traditional drive systems. As the engine turns the primary clutch, the weights will experience rotational momentum and will compress the primary clutch. Since the belt is of a fixed length and the effective radius around the primary clutch increases as it compresses, the secondary clutch's effective radius decreases. In doing so, the CVT approaches a "high to low" orientation (Fig. 2) and so goes to a low gear reduction, simulating a "high gear" in a traditional drive system.

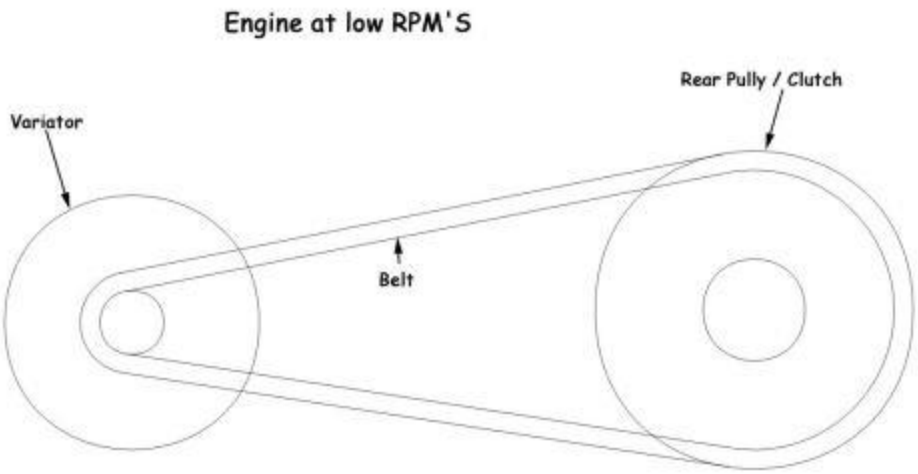

Fig. 1: initial stage of CVT. Note that the Variator in this image is the same as the primary clutch and the rear pully/clutch is the same as the secondary clutch
Source: http://flexistentialist.org/blog/archives/2003/10/27/cvt-basics-constant-variable-transmissions/

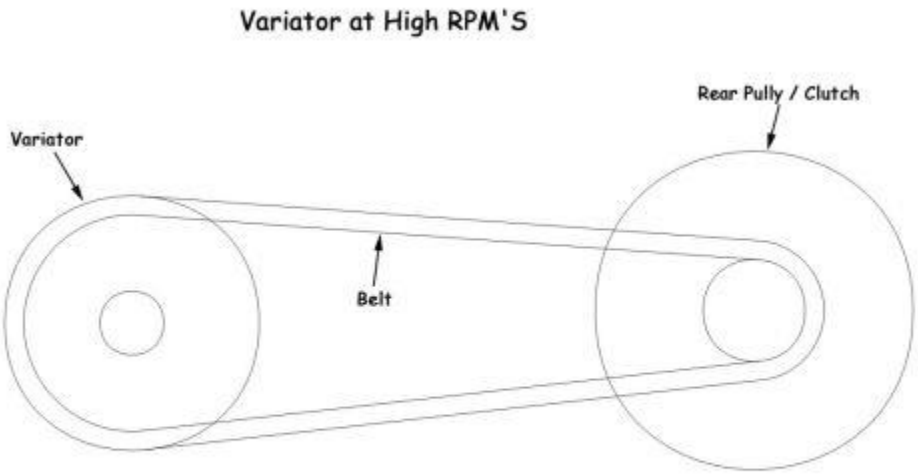

Fig. 2: final stage of CVT. Note that the Variator in this image is the same as the primary clutch and the rear pully/clutch is the same as the secondary clutch
Source: http://flexistentialist.org/blog/archives/2003/10/27/cvt-basics-constant-variable-transmissions/

Note: the GX-9 system's initial ratio is 3.9 and the final ratio is 0.9 meaning that the final ratio is actually a gear multiplier, not reducer. This decreases the torque to the wheels but increases the speed at which the wheels spin based on input of the engine.

Adjustment Parameters: Of the parts in the CVT, the parameters most accessible and versatile to adjust are the belt, weights, helix, and contra spring. At a competition, the only factor that can be adjusted without extensive time and effort is the belt since the other three can only be adjusted by disassembling their respective clutches.

Weights: Weights in the primary clutch are essential for the contraction of the clutch. As the weights in the primary are changed to get heavier, the clutch will ride up the helix and contract faster, therefore leading to a faster shift speed.

Contra Spring: This spring is to resist the expansion of the secondary clutch, which is a result of the primary clutch contracting. After a driver eases on the throttle and the engine's input decreases, this spring pushes the secondary clutch back together to revert the CVT system back towards its initial orientation. There are two ways to change the stiffness of this spring: Firstly, different springs with different k constants can be used or secondly, the spring can be prestressed by twisting during installation.

Note: There is a general direct relationship between weights and the stiffness of the contra spring, i.e. as weight increases, the stiffness of the spring should increase as well. If there is too much weight, the CVT will not revert to the initial orientation, meaning the transmission will stay in a "high gear" and will not be able to produce the appropriate torque when the throttle is opened again. Alternatively, is the spring is too stiff, the CVT will not shift.

Helix: The helix (Fig. 3) is to guide the expansion of the secondary clutch by directing the twist of the secondary clutch expansion. The steeper the angle, the easier the secondary can expand, leading to faster shift time.

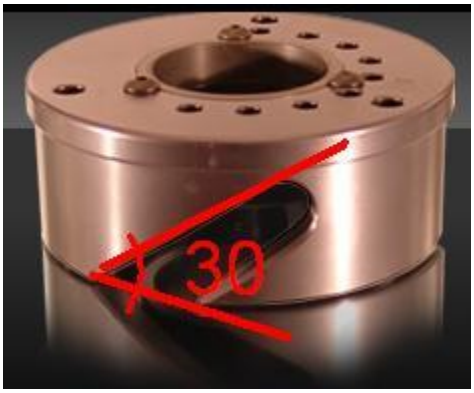

Fig. 3: A CVT helix. This one has an incline angle of 30 degrees.
Source: http://forums.bajasae.net/forum/uploads/368/helix_cam.JPG

Note: This SAE Baja team uses a helix from Gaged that employs two angles: a steeper angle leading to a more gradual angle. The result is a fast start to shifting then a more gradual shift later on.

Belt: The point of interest in the belt is the tension of the belt. If the belt is too loose around the clutches, the primary clutch will need to spin at a higher rate (higher engine input) to contract

first to engage the belt. This would mean effective idle RPM of the vehicle would be raised. An overtightened belt would engage too quickly and could cause the belt to stretch, overheat, or rip. Note: the belt used by this team is designed for an 8.5 inch center to center distance between the clutches.

Power vs. Torque: When looking at data from an engine, the two greatest factors to see are the power and torque. Torque is what is needed to turn the wheels but power is the desired object in the engine, more so than high torque because power speaks to the speed at which work is performed [Hotrod]. When looking at the torque provided by the engine and power provided by the engine across RPM, it should be noted that both values rise to a peak and then drop towards highest RPM as seen in Fig. 4. It is best to maximize power when looking in the performance of the engine, though it is generally understood that an increase of power will lead to an increase in torque.

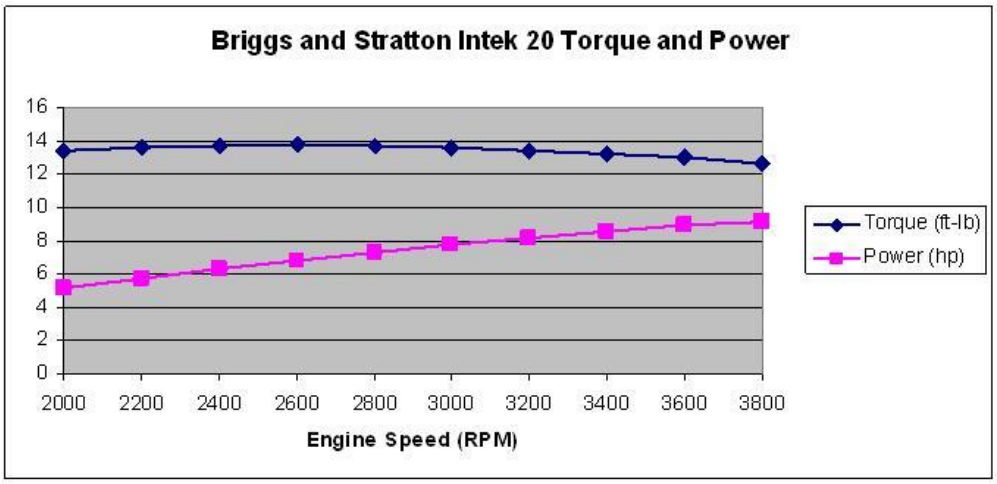

Fig. 4: Power and Torque curves for the Briggs and Stratton Model 20 Engine

Somewhat fortunately, SAE Baja teams do not need to worry much about finding ways to maximize the power in the engine since any tampering with the engine is prohibited by SAE. If anything, air can be channeled into the engine to raise the engine's power band but the effectiveness of this at the speed of SAE Baja vehicles is not thoroughly tested or verified by this team.

Tuning in the CVT: Keeping in mind the adjustable parts of the CVT and the objective of maximizing power in the drivetrain, it is clear to see that the CVT should aim to hold the engine at peak power. Through the function of the CVT's shifting, it can keep the engine at a constant RPM. That magical value is the RPM at which the engine has maximum power.

Note: As of the 2017 SAE Baja Competition season, the mandatory engine is the Briggs and Stratton Model 19 Engine. For this engine, the literature value for peak power occurs at 3600 RPM. This value is right before the throttle hits the governor, which causes the fuel supply to be cut, forcing engine RPM to lower.

Now that the target is known, the RPM of engine should be mapped as the throttle is opened up and a result similar to Fig. 5 may be seen.

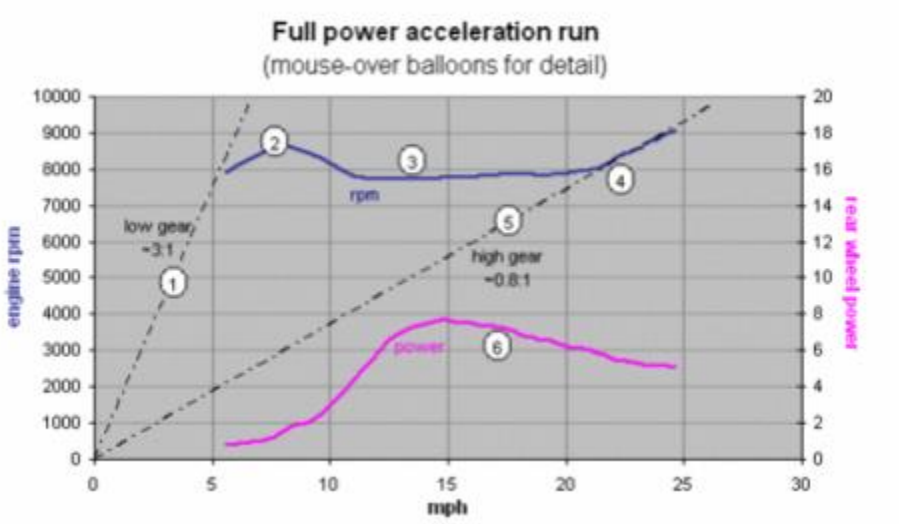

Fig. 5: Acceleration test of vehicle with CVT
Source: http://www.apexatv.com/techsupport/apexclutch.pdf

The RPM should spike at first as the belt engages and initiates the natural function of the CVT. Then, the RPM of the engine should stay level around a single value. If this value is where the peak power of the engine occurs, the CVT is properly tuned, otherwise, try to adjust parameters as appropriate.

Another way to tune the CVT and to validate proper results is to run an SAE Baja style acceleration and try to minimize the time to complete the course by adjusting parameters of the CVT. Once the minimal time is reached, the CVT should engage such that the engine stays at peak RPM.

Note: Once the CVT is fully shifted, the RPM of the engine will continue to increase as would any more traditional drivetrain at its "high gear" setting.

Sources:

[1] http://flexistentialist.org/blog/archives/2003/10/27/cvt-basics-constant-variable-transmissions/
[2] http://www.apexatv.com/techsupport/apexclutch.pdf
[3] http://www.hotrod.com/articles/hrdp-0401-torque-horsepower-guide/
[4] http://www.briggsandstratton.com/cn/zh/~/media/Frequently%20Asked%20Questions/Engine/PDFs/Antique%20Manuals/Antique%20Manuals%20FAQ%202/Model%2019-domestic.pdf