CVT: Thoughts and a Proposed Design

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Abstract

This document is a collection of my initial thoughts and ideas on CVT systems, their uses, what we want from them, and my idea for one. My idea is a dual-differential CVT system, which is a single-input and single-output CVT system that uses two differentials: one to split the input power into a high and low speed reducers (creating a power differential) and one to combine them again. It may have been done before (and I have found evidence for this), but I believe those explorations lack depth.

1 Why are CVTs Useful?

1.1 Mechanical Power

The mechanical power of some rotating thing is given by the following equation:

$$P_m = \tau * \omega \tag{1}$$

You can think of τ (torque) and ω (speed) as the length and width of a rectangle, the rectangle would have an area of P_m.

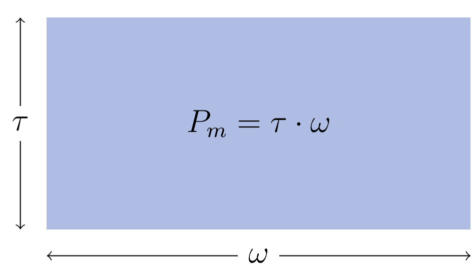

Figure 1: Rectangular representation of mechanical power.

If we fixed P_m, there would be an infinite number of rectangles with this area, and thus there are an infinite number of $\tau : \omega$ ratios for any P_m. Each of these rectangles is representative of one single gear ratio.

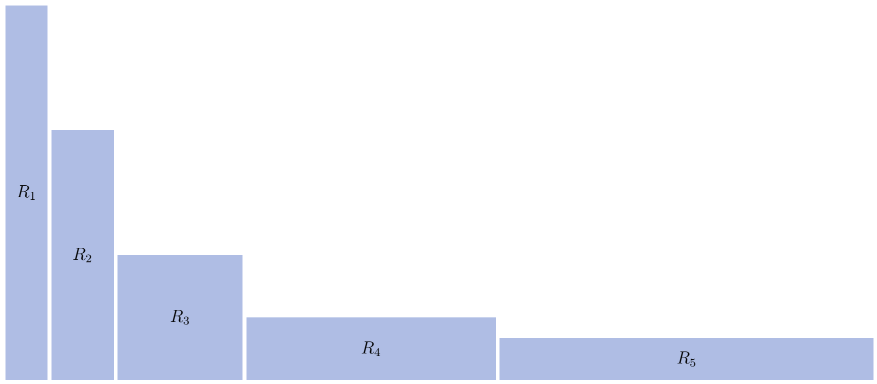

Figure 2: Various examples of rectangles with the same area P_m.

Lets say there's a constant torque-speed combination given by our motor (our input, which we have to manipulate for our needs), given by the case where the rectangle is a square (generally the case for a motor's maximum power output, which we will discuss later). This is the middle rectangle, R_3, in Figure 2, which has a $\tau : \omega$ ratio of $1 : 1$, direct drive! There is no gear reduction yet.

R_1, which has a $\tau : \omega$ ratio of $9 : 1$, would represent a $1 : 3$ reduction, we are tripling the torque, but our output speed is $\frac{1}{3}$ of the input.

Layering these rectangles gives us a crude approximation of a curve, where each ω (x-axis) has a corresponding τ (y-axis):

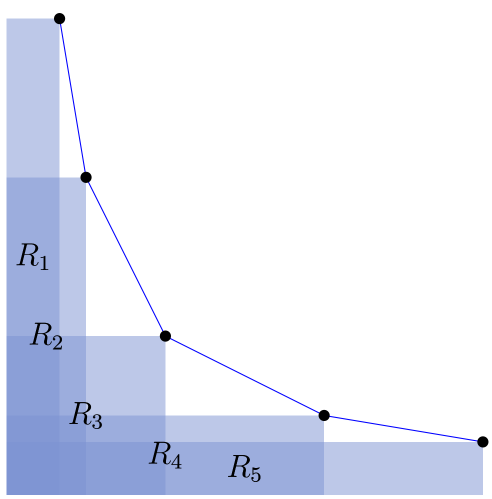

Figure 3: Crude approximation of optimal power graph with 5 rectangles.

Depending on the torque requirements, you could choose between discrete reduction ratios. This is how a conventional bicycle works with its chain and sprocket transmission and manual gear shifter.

If we had a bike transmission with an infinite amount of these sprockets, we wouldn't have to choose between a handfull of discrete, sub-optimal reduction ratios. Instead, we could just choose the exact ratio for our requirements. This is the idea for a CVT. Specifically extending the bicycle example, we would end up with something like the V-Belt CVTs we currently use in some cars.

We can bring this CVT idea back to the torque-speed graph by adding more and more rectangles (approaching infinity), giving us a continuous curve. This type of curve is aptly named: it is a rectangular hyperbola.

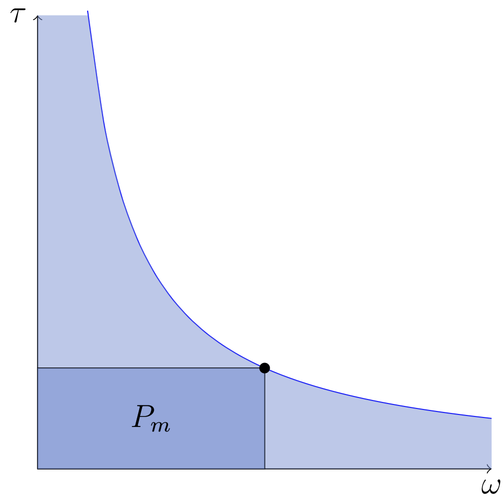

Figure 4: Optimal torque-speed curve with a constant P_m

This curve, the rectangular hyperbola (aka: $y = \frac{1}{x}$), is the ideal torque-speed curve in terms of power, we are always at peak performance. The function for this curve is

$$\tau = \frac{P_m}{\omega} \tag{2}$$

Remember that P_m is a constant.

1.2 Torque-Speed Curve of a Motor

One thing that can help our intution for this curve is looking at the torque-speed curve of a motor.

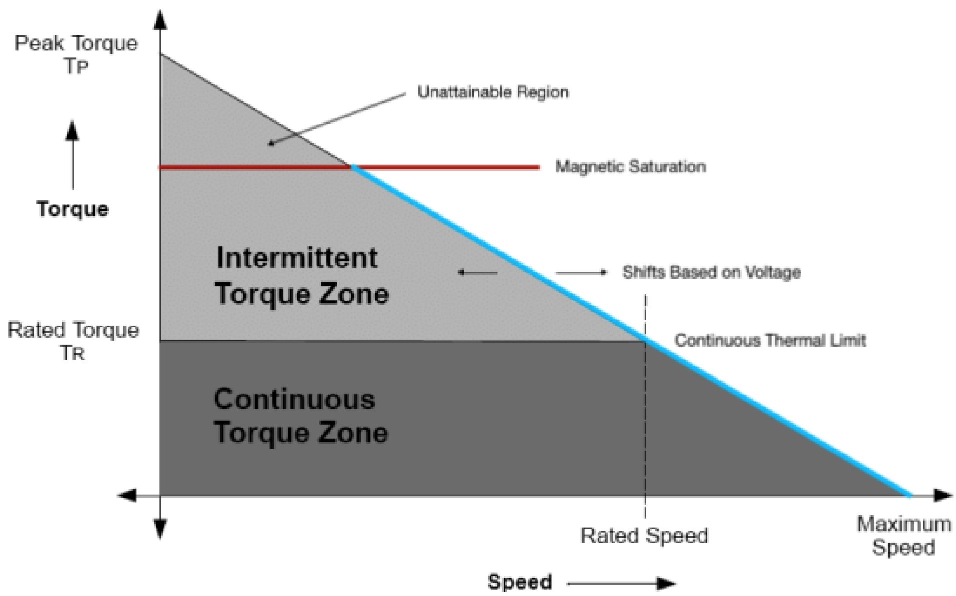

Figure 5: Torque-speed curve of a motor from Adi Mehrotra's Dynos for Dummies

This curve is a simple linear function, connecting the y-intercept (peak torque τ_p or $\tau_{\max}$) to the x-intercept (maximum speed $\omega_{\max}$).

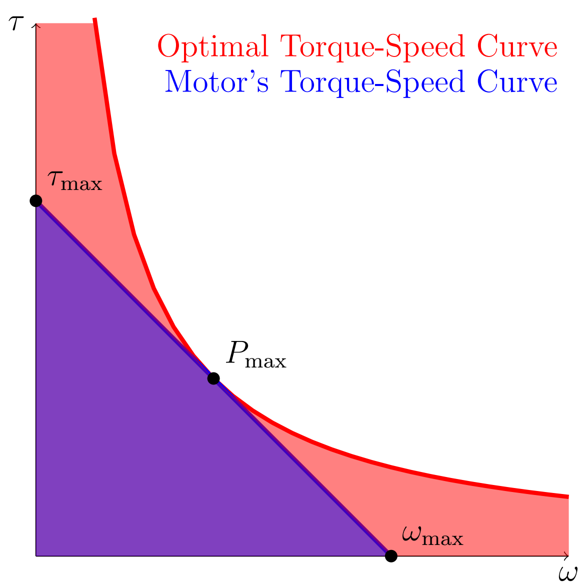

Figure 6: Rectangular hyperbola and motor torque-speed curve.

If you compare this to the rectangular hyperbola, we see that there is one point where they intersect, which is also the point of maximum power output for a motor.