Gates Carbon Drive System

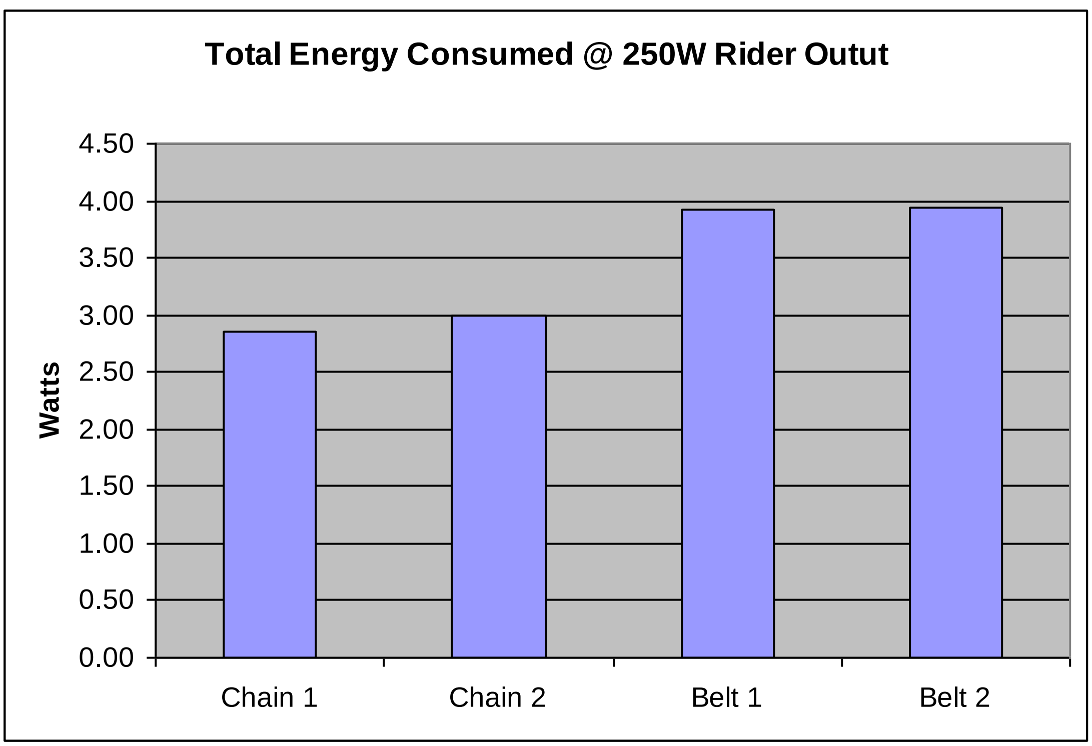
vs.

Traditional Chain Drive

Efficiency Test

SUMMARY OF RESULTS:

The results show the Gates Carbon Drive System (CDS) **consumes 34.6% more power** when compared to a traditional single speed chain drive. The chain drive frictional losses are **2.92 watts** average. The CDS frictional losses are **3.93 watts** average. The test was performed at 250W load, using similar diameter rings, similar diameter cogs, with the CDS installed per manufacturer's 85lb preload guidelines, with chain installed at 2lb preload.



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TEST DETAILS:

The goal of the test was to determine the efficiency of the single speed Gates Carbon Drive System compared to the traditional single speed chain drive.

TEST PRODUCTS:

Two chain samples and two belt samples were tested. Chain 1 is a Shimano CN7901 (Dura Ace Group 10sp). Chain 2 is a SRAM PC1091R (Red Group 10sp). Belts 1 and 2 are each similar model Gates CDX belts, 10mm width, 125T, p/n 11M-125T-10.
For the chain test, a 53T FSA front ring (107mm effective radius), and a 19T SRAM rear cog (78mm effective radius) were used.
For the belt test, a Gates 60T CDX front ring (106mm effective radius), and a Gates CDX 22T rear cog (79mm effective radius) were used.
Due to the different pitches of the belt (11mm) and the chain (12.7mm), different tooth-count rings and cogs had to be utilized in order to achieve similar effective ring and cog radii.

TEST METHOD:

This test utilized the Full Tension Test (FTT) Method. Details on the FTT can be found at www.friction-facts.com/equipment.

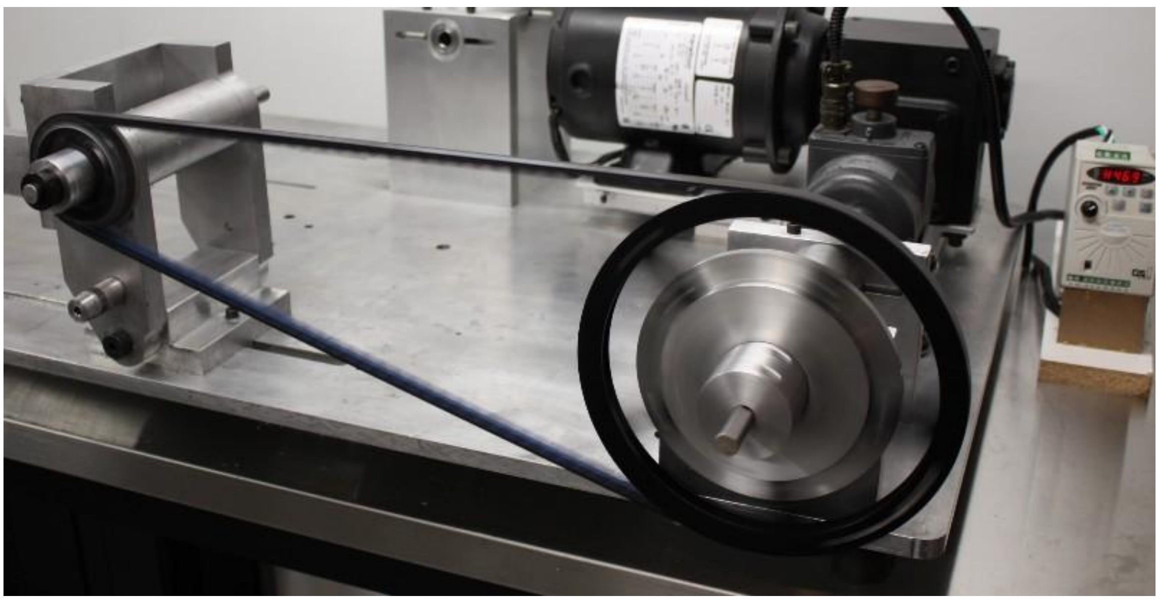
This test was unique from the other chain tests performed by Friction Facts. In previous chain tests, the Full Tension Tester was typically set at a span tension simulating 250 watts rider output. All chains were tested equally, and data reported across the same tension. In this test, however, the CDS requires substantial tension preloading, which does not allow simple same-tension comparisons to evaluate the friction of each of the two systems at the same rider output.

The governing factor of the CDS friction is the preload tension (i.e., the friction found in the CDS is an effect of the preload, and not an effect of the tension created by rider output torque). Conversely, with a chain drive, the tension created by the rider output torque is the main driver of the friction. Preload is minimal in a chain drive and likewise affects the friction minimally.

Hence, for a given rider output, the chain drive and CDS cannot be compared equally at the same span tension points on the data graph. However, they each can be compared at the respective drive system's *unique span tension value* given the same rider output wattage. When evaluating the losses at 250W rider output, the chain drive must be evaluated at its specific yet unique total span tension at 250W rider output, while the Gates CDS must be evaluated in a similar manner at its specific yet unique total span tension at 250W rider output. This is explained in greater detail below.

ADDITIONAL DETAILS:

- 95RPM cadence
- The belts were subjected to 1hr of run-in at 250W prior to testing.
- The chains were subjected to 1hr of run-in at 250W prior to testing. Both chains were cleaned and re-lubed with basic light bearing oil.
- Tension per span values are actual, not calculated, and measured at the span. Total Span Tension on the graph below is the sum of the top span and bottom spans. E.g., for the CDS, the often-referenced 85 pounds per span tension equals 170 pounds Total Span Tension on the graph.
- The accuracy of the Full Tension Tester is +/- 0.02 watts.
- The system losses (the losses from the ceramic bearings used in the test equipment) were removed from the final results seen in this report.

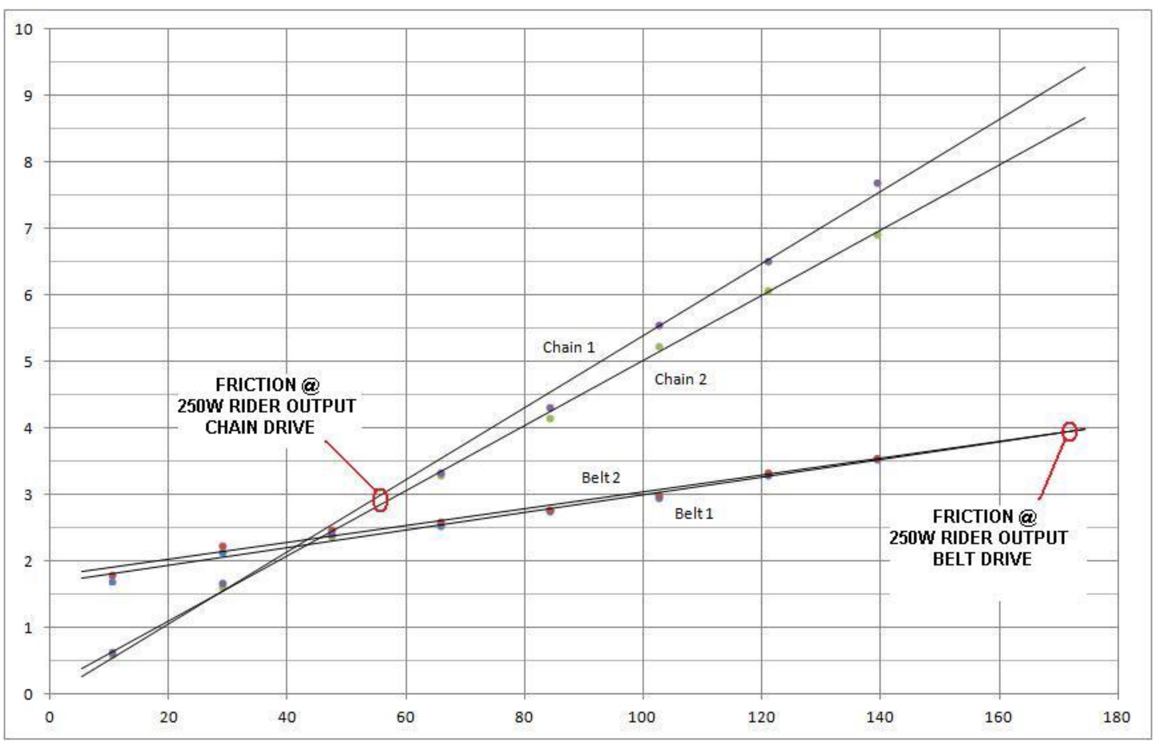


Pic 1: Gates CDS during test.

Calculation of Span Tension at 250W Rider Output:

Chain Drive: Using 250W steady-state output, 95RPM, and moment arm of 107mm (effective radius of a chain 53T ring), the tensile force in the top chain span due to rider output torque is 52.81 pounds. For the purposes of this calculation, it is assumed the chain is preloaded statically with 2 pounds per span. When the bike is in dynamic operation (rider pedaling), the top span is subjected to 54.81 pounds. This quantity is the 52.81 pounds tension from rider output, plus the 2 pound preload tension. The bottom span tension is subjected to 1 pound in dynamic operation. The 2 pounds of tension seen previously on the bottom span due to the static preload is eliminated when the rider output torque is applied. Essentially, with minimal preload, the bottom span becomes slack during pedaling. However, even with a slack chain, the weight of the chain itself creates light tensile forces. 1 pound is used for the tension created by the hanging weight of the chain for this calculation. When summing the top and bottom span tensions, the total span tension is 55.81 on the chain drive. By using the Span Tension vs. Watts graph below, **the chain drive averages 2.92 watts friction @ 55.81 pounds.**

CDS: Using 250W steady-state output, 95RPM, and moment arm of 106mm (effective radius of a Gates 60T ring), the tensile force in the top chain span due to rider output torque is 53.30 pounds. For the purposes of this calculation, a static preload of 85 pounds per span is used. This is the manufacturer's recommended preload for higher output riders. When the bike is in dynamic operation, the top span is subjected to 138.30 pounds. This quantity is the 53.30 pounds tension from rider output torque, plus the 85 pounds of preload tension. The bottom span is subjected to 31.70 pounds during dynamic operation. This quantity is the negative tension created by the 53.30 pounds of rider output torque plus the 85 pounds of preload. When summing the top and bottom span tensions, the total span tension is 170 pounds on the CDS. By using the Span Tension vs. Watts graph below, the **CDS averages 3.93 watts friction @ 170 lbs**. Note the tension specifically created by the 250W rider output torque does not affect the final total tension in the system. The final total tension in the CDS is governed solely by the large preload.



Graph 2: Total Span Tension (lbs, x-axis) vs Friction (watts). Total Span Tension is the sum of the top span and the bottom span tensions.

Belt vs. Chain Efficiency; Investigated with No Preload:

If preloading was not a factor of either drive system, when the performance of the belt is compared to the performance of the chain at similar tension values, with all test parameters being equal, the CDS belt actually becomes more efficient than the chain at given span tensions above 21.90 lbs/span (43.80 lbs total span tension). It must be noted, however, that preload is a present requirement, per the manufacturer, for the CDS system to operate properly. This section investigates the physical properties of the belt drive beyond the typical installation.

As shown in the above graph, the chain and belt friction both act in a linear fashion when compared to span tension. The belt exhibits 1.73 watts friction when no tension is applied to the belt (zero offset). The chain approaches zero watts friction when no tension is applied to the chain. However, when looking at the average slope of friction/tension, the slope of the belt is considerably lower than the slope of the chain, by a factor of approximately 4. At span tension over 21.90 lbs/span (43.80 lbs total span tension), the belt begins to become more efficient than he chain drive, and continues to increases in efficiency in a linear manner as the span tension increases. When stated from a different perspective, the frictional losses of a chain drive increase with span tension four times faster than that of the CDS.

This finding is significant. To summarize, when the belt drive is tested as a 'system', with the high preloading, the belt drive will always be less efficient than a chain drive, regardless of the rider power output (see explanation below). The belt, however, when compared to the chain *at the same tension levels*, becomes more efficient than the chain as the tension increases.

Efficiency of the CDS at Any Rider Output Wattage:

Even with the manufacturer's preload guidelines, at first glance of the watts vs. tension graph it might seem plausible at some finite higher tension, considering the chain's friction slope is four times greater than the belt's slope, the belt drive system will become more efficient than the chain drive system. This in fact would be the case if preload of the CDS was capped at 85 lbs/span.

However, this is not the case. Two issues exist that make the CDS less efficient than the chain drive regardless of the rider output, when installed with the necessary preload. First, the preload must always be increased accordingly to accommodate higher output riders. The preload requirements exist to keep the lower span from skipping on the cog (in dynamic operation, the total bottom span tension equals preload tension minus tension due to rider output torque). As rider output torque increases, so must the preload tension, in order to keep a net positive tension of some magnitude on the bottom span. Secondly, the 250W rider output torque referenced in this report has been considered a steady state torque through a full rotation of the crank. In a real world situation, a rider's torque output varies through one full rotation, with the instantaneous torque peaks typically occurring during the leg down strokes.

This peak torque can be over 5 times higher than the steady state value. For example, during hard acceleration or sprinting, the peak torque of a 250W threshold rider can easily hit 1000 watts for a fraction of a second. Knowing that the belt drive system must accommodate peak torques to prevent belt skipping, not only steady state torque, the preload requirements become even larger.

Because of these two factors, the need for increasing preload to accomodate increasing rider output will always cause a CDS to perform less efficiently than a chain drive system at similar rider output wattage.

Looking Ahead: Potential Means of Increasing the Belt Drive System Efficiency:

As discussed earlier, the requirement for belt preloading exists to ensure the belt engages into the cog teeth with minimal belt skipping. However, preload is the governing factor and directly proportional to belt drive efficiency.

A chain also requires preloading to ensure engagement in the cog, but this preload can be minimal. In many instances, the tension created simply from the weight of the chain hanging in the span is enough preload to keep the chain engaged on the cog.

In theory, if a belt drive system was able to operate in a similar manner to a chain drive system with respect to tension, i.e., with low or no preloading requirements, the belt drive system would theoretically be more efficient than a chain drive at all rider outputs greater than 208 watts. 208 Watts is the equivalent tension (approximately 44 lbs) at the intersection of the chain and CDS friction-tension lines on the graph.

For example, if a belt drive system was designed in which the preload was comparable to a chain system, the friction of the belt drive at 400W rider output would be 37% less than the friction of chain drive. At 400W rider output and similar span tensions, friction is 2.86 watts for the belt drive and 4.56 watts for chain drive.

It appears this concept will be put to use in Continental’s soon-to-be-released belt drive system. Per the manufacturer’s press release, this system uses taller teeth to assist in belt/cog engagement with the intended effect of keeping the preload lower, to increase efficiency. Unfortunately, at the time of this writing, the Continental system has not yet been released and therefore was not tested.

A second proposed concept of reducing belt drive friction is to incorporate a small roller at the point of engagement of the bottom belt span to the cog. The roller would be spring loaded in a manner to provide constant force acting to push the belt teeth into the cog, ensuring engagement of the belt teeth. If this proposed roller was able to prevent the belt from skipping without relying on substantial preload, this concept could possibly achieve effective span tension levels similar to a chain drive, and therefore create lower friction than a chain drive above approximately 208 watts rider output. The friction created by the roller pushing on the belt would likely be in the range of .05 watts. This would be a beneficial trade-off if the roller is able to minimize or eliminate bottom span preload and the friction associated with the preload. This is pure speculation. Perhaps other real world factors would have to be considered when investigating methods to reduce preload on a belt drive.

Appendix: Data Points

Tension/Span (lbs)	5.24	14.44	23.65	32.86	42.06	51.27	60.48	69.68
Total Span Tension (lbs)	10.48	28.88	47.3	65.72	84.12	102.54	120.96	139.36
Belt 1 (watts)	1.71	2.15	2.4	2.54	2.76	2.97	3.30	3.54
Belt 2 (watts)	1.81	2.24	2.48	2.61	2.79	3.01	3.35	3.56
Chain 1 (watts)	0.60	1.62	2.38	3.3	4.15	5.24	6.08	6.91
Chain 2 (watts)	0.64	1.69	2.43	3.35	4.32	5.57	6.53	7.70

