OVERSIZED PULLY WHEEL SYSTEM

REPORT AND GENERAL INFORMATION

This document contains four sections.

Section 1: How does an oversized pulley wheel system decrease drivetrain friction?
Section 2: What to look for in an oversized pulley wheel system design
Section 3: Test data for the CeramicSpeed-specific OSPW
Section 4: The original un-edited Friction Facts Oversized Pulley Wheel Report (2013 report, produced before the merger of CeramicSpeed and Friction Facts)

SECTION 1: How does an oversized pulley wheel system decrease drivetrain friction?

Oversized pulley wheel systems can decrease the friction in a drivetrain by utilizing four distinct factors.

1) Larger Pulley Wheels:
    a. Larger pulley wheels decrease the level of articulation in each chain link as the chain engages and disengages the pulley wheels. For example, an 11-tooth pulley wheel causes each link to articulate 33 degrees as it enters and exits each pulley wheel. Whereas, a 19-tooth pulley wheel causes each chain link to articulate 19 degrees. When a chain link is forced to articulate under some level of chain tension (see more on this below), friction is created at the pivot point by the sliding surfaces within the link. If a link is forced to articulate to a lesser degree, this results in decreased friction.
    b. Larger pulley wheels spin at a lower RPM, and subsequently the pulley wheel bearings spin at the same lower RPM. The friction created by a bearing is directly related to the spin speed. Therefore, a slower-spinning bearing decreases friction.

2) High-efficiency Bearings: The friction created in bearings is dependent on the quality of the races, balls, and cage, on the dimensional design of the aforementioned, the type of seals, and the type & pack level of the lubricant. Additionally, oversized pulley wheel systems, given the larger pulley wheels, can place slightly higher off-rotational-axis loading (moment loading) onto the bearings than with typical smaller pulley wheels. Bearing design should be considered and included as one of the four factors. A highly-efficient, well designed bearing will decrease friction.

3) Rear derailleur cage tension: A lower cage tension decreases the chain tension of the three lower spans. Chain tension is directly proportional to friction. As mentioned above, when the chain links articulate into and out of the pulley wheels, lower chain tension decreases the friction created by each link. Therefore, lower cage tension decreases the friction of the system.

Note in the first line of this section, the statement appears: oversized systems "*can*" decrease the friction. The friction savings provided by an oversized pulley wheel system are not absolute. Friction savings can vary, based on how many of the above factors are incorporated into an oversized system design, and to what extent.

Section 2: What to look for when selecting an oversized pulley wheel system

Because a given oversized pulley wheel system might have larger pulley wheels, doesn't necessarily mean that a specific oversized system will decrease friction. It is very possible an oversized pulley wheel system could create more friction than the stock cage it is replacing.

Say, for example, an oversized pulley wheel system, which indeed has the obvious larger pulleys, also has very inefficient bearings or bushings (less efficient than the bearings in the stock cage). The efficiency losses of the bearings in the larger pulley wheels will outweigh the efficiency gains from the larger pulley wheels themselves.

Likewise, for example, if the cage tension of an oversized system is too high, the same effect will occur; losses will outweigh the gains from the larger pulley wheels.

With this in mind, it is important not to assume an oversized pulley wheel product will always decrease the efficiency of the drivetrain. It is good to be skeptical of oversized products. All oversized pulley wheel systems are not the same. A prudent consumer desiring to increase drivetrain efficiency should look beyond the single factor of larger pulley wheels and investigate the complete package; each and all the factors that can make an oversized system fast.

Always consider-

1) Pulley sizes (tooth count). Bigger is always better, when considering the friction created by chain articulation. Additionally, the larger the pulleys, the lower the bearing spin RPM. Ie, a 19-13T will be faster than a 15T-13T, if all other factors are equal.
2) Has attention been given to the PW tooth shape, profile, and cut? Highly efficient pulley wheels, regardless of the size, have distinctive tooth profiles and edging. This increases efficiency and also provides better shifting characteristics. Picture a cross-chained chain entering a lower pulley wheel. The chain slides onto a rounded/chamfered tooth edge with less friction than a square edged tooth.
3) What about the bearings themselves? As mentioned above, large pulley wheels with bad bearings can offset any potential gains. High quality highly-efficient bearings are desirable. Bearings designed for the moment loads of larger pulleys are desirable.
4) What types of bearing seals are being used? Thicker, heavy-contact seals can be easily and inexpensively produced, yet this type of seal creates increased friction from race-to-seal rubbing. Light-contact seals are desirable, as these types of seals minimize rubbing friction and still provide a high level of contamination protection.
5) What type of grease is used in the bearings, and at what pack level? A thicker, low quality grease with a 100% pack level will create additional friction. Whereas, a grease selection optimized for the RPM and forces of the bearing, with the proper lower pack level, will maximize efficiency.

6) What amount of cage tension does the oversized pulley wheel system create? Lower cage tension is better, yet cage tension must be perfectly balanced to minimize chain span tension (in order to decrease chain friction) yet not allow the chain to jump off the PWs. Some oversized systems will use higher cage tensions to compensate for poor shifting performance. This negates the potential efficiency gains. An oversized system with low cage tension, or with user-selectable low-to-high tensions is desirable.
7) Has the oversized pulley wheel system been tested for friction? This is probably the most important question a potential buyer should be asking themselves. As shown in this document, numerous factors must come together to make a fast oversized system, but when all is said and done, does the specific oversized system truly decrease friction as intended? Qualification testing can show this, if it has been performed.

Beyond decreases in friction and efficiency gains, one should consider these points:

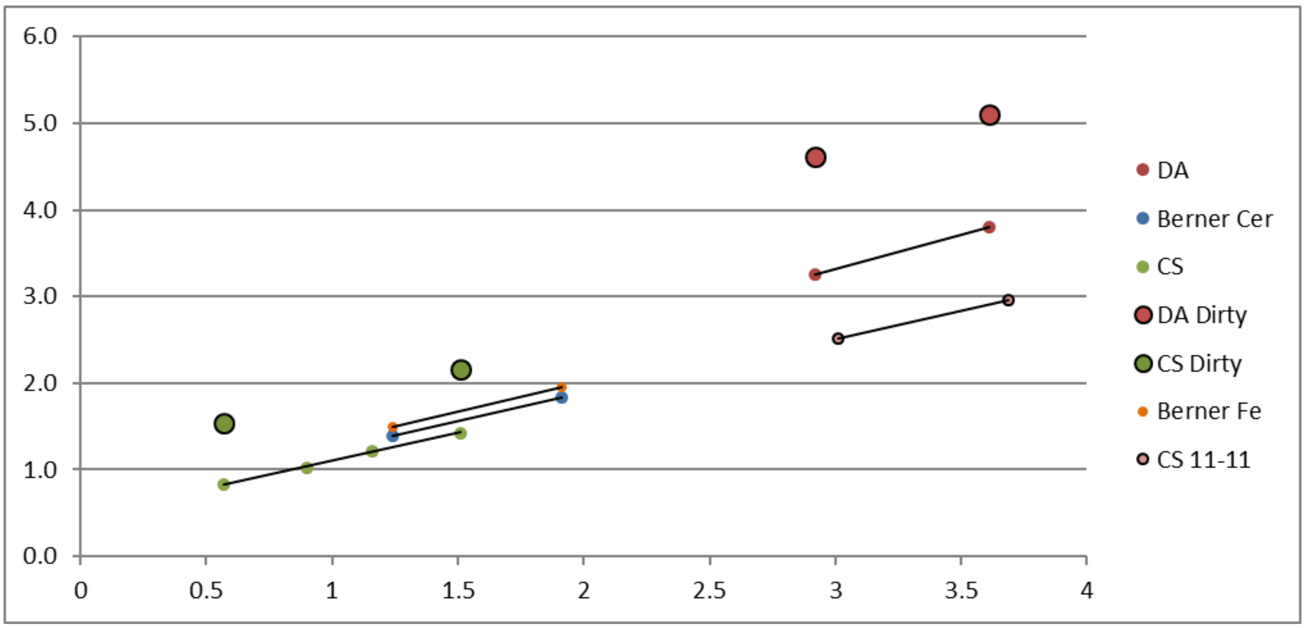
1) How difficult is the oversized pulley wheel system to install? Does the oversized system come with detailed installation guidance and support?
2) Once installed, will the oversized system shift smoothly and provide an enjoyable ride?
3) General build quality of the cage structure?
4) The expected longevity of the system?
5) Does the manufacturer provide a warranty? If so, how long is the warranty?
6) What is the manufacturer's experience with oversized pulley wheel systems and reputation?

Prices of oversized pulley wheel systems vary greatly. Much of the price of an oversized depends on the design and build quality.
More often than not, higher-priced oversized systems take into consideration more of the above friction-reducing factors than lower-priced options.

Ultimately, the goal of this section is to provide to a potential buyer on the details of what might matter (or not matter) in an oversized pulley wheel system, in order to make an educated buying decision. After all, there's a lot more to an effective oversized system than simply big pulley wheels.

Section 3: Test data for the CeramicSpeed-specific OSPW:

(Background- In 2013, Friction Facts performed the 'original' oversized pulley wheel system test sequence. This test compared a Berner oversized system and RAL oversized pulleys to stock smaller pulley wheels. These two products were, at that time, the only oversized product available to the consumer. This original test is posted below, in Section 4 of this document. In 2014, Friction Facts performed substantial testing of the to-be-released CeramicSpeed OSPW system. Below, the highlights of the CeramicSpeed OSPW testing data are overlaid onto the pre-existing data from the original FF report.)



Various oversized systems, stock, and modified cages, in clean and dirty conditions.
DA= stock Dura Ace; DA 11T pulley wheels and DA cage
Berner= Berner oversized system; Berner large pulley wheels with Berner cage
CS= CS OSPW; CS large pulley wheels with CS cage
CS 11-11= CeramicSpeed 11T PWs installed into a DA cage

Key takeaways:

- The CS OSPW creates 0.83 watts on the lowest cage tension setting and 1.43 watts on the highest cage tension setting. Compare this to a stock Dura Ace which creates 3.25 watts and 3.80 watts, low and high respectively.
- Note the linear correlation of cage tension vs. friction.
- Note the deltas between a clean and dirty chain, between the CS and DA system. The CS light, clean vs dirty, is 0.71 watt delta. The DA light, clean vs dirty, is a 1.37 watt delta. This shows that the increase in friction due to a dirty chain is higher on a stock DA vs the CS OSPW. This happens because more friction is created as the smaller PWs force the dirty chain to articulate to a greater degree, than a larger pulley wheel articulating the same dirty chain. Therefore, the

CS OSPW is not only faster than a DA with a clean chain, but does not increase as much as the DA as the chain picks up road contamination.

Data:

RD System	Norm Watts	Chain Tension	Cage Setting
DA 11-11 Heavy	3.80	3.61	Heavy
DA 11-11 Light	3.25	2.92	Light
Berner 13-15 Cer Heavy	1.83	1.91	Heavy
Berner 13-15 Cer Light	1.39	1.24	Light
CeramicSpeed 17-17 Heavy	1.43	1.51	Heavy
CeramicSpeed 17-17 Mid-Heavy	1.22	1.16	Mid-Heavy
CeramicSpeed 17-17 Mid-Light	1.03	0.9	Mid-Light
CeramicSpeed 17-17 Light	0.83	0.57	Light
DA 11-11 Heavy Dirty	5.11	3.61	Heavy
DA 11-11 Light Dirty	4.62	2.92	Light
CeramicSpeed 17-17 Heavy Dirty	2.17	1.51	Heavy
CeramicSpeed 17-17 Light Dirty	1.54	0.57	Light
Berner 13-15 Steel Heavy- calc	1.96	1.91	Heavy
Berner 13-15 Steel Light- calc	1.49	1.24	Light
CS 11-11 with DA cage light*	2.52	3.01	Light
CS 11-11 with DA cage heavy-calc	2.96	3.69	heavy

Section 4: The original un-edited Friction Facts publicly-released oversized pulley wheel system report (2013)

OVERSIZED DERAILLEUR PULLEY

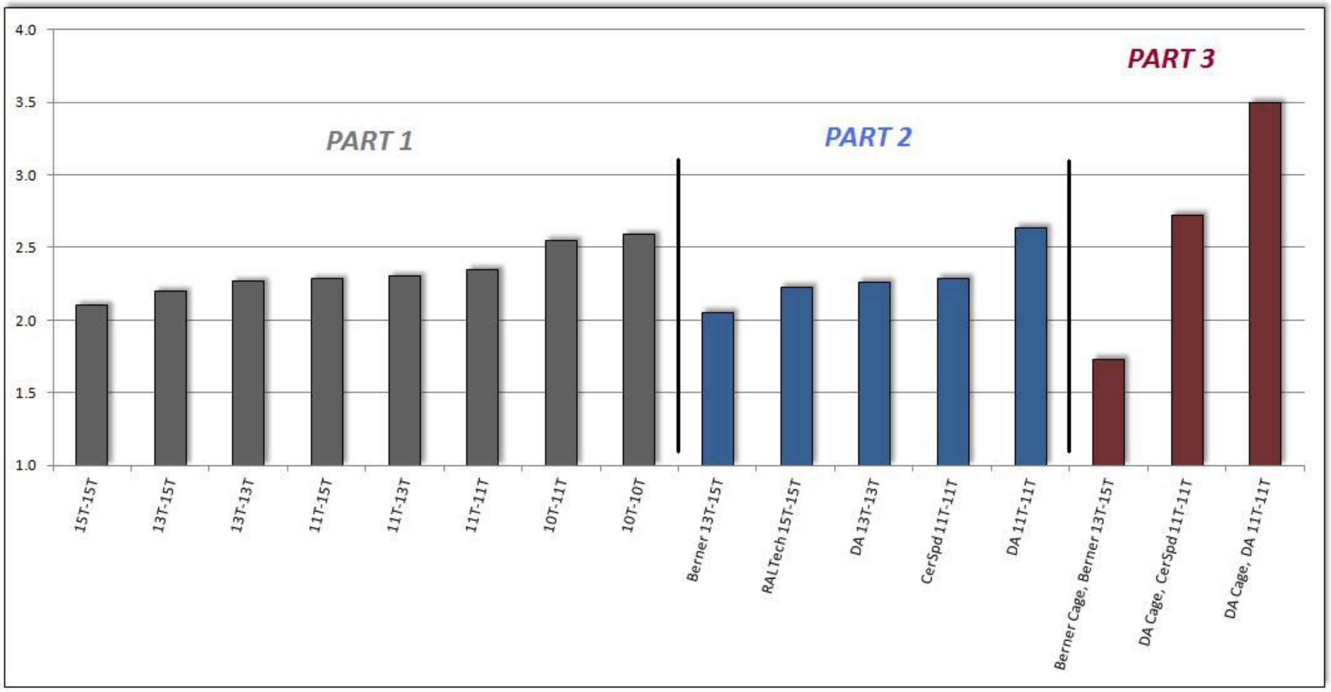
EFFICIENCY TEST

SUMMARY

0.49 watts efficiency difference was measured between a 10T-10T pulley combination and a 15T-15T pulley combination, with chain tension and bearing variables held constant.

This data positively confirms the general theory of decreased friction with increased pulley diameter, with all other variables excluded.

With cage tension and bearing variables introduced, a **1.76 watt** efficiency difference was measured between the best and worst performing derailleur 'systems' (a 'system' includes the manufacturer's cage, pulleys, and bearings within the pulleys), namely the Berner 13T-15T pulley/cage combination being the most efficient and the Dura Ace 11T-11T pulley/cage combination being least efficient.

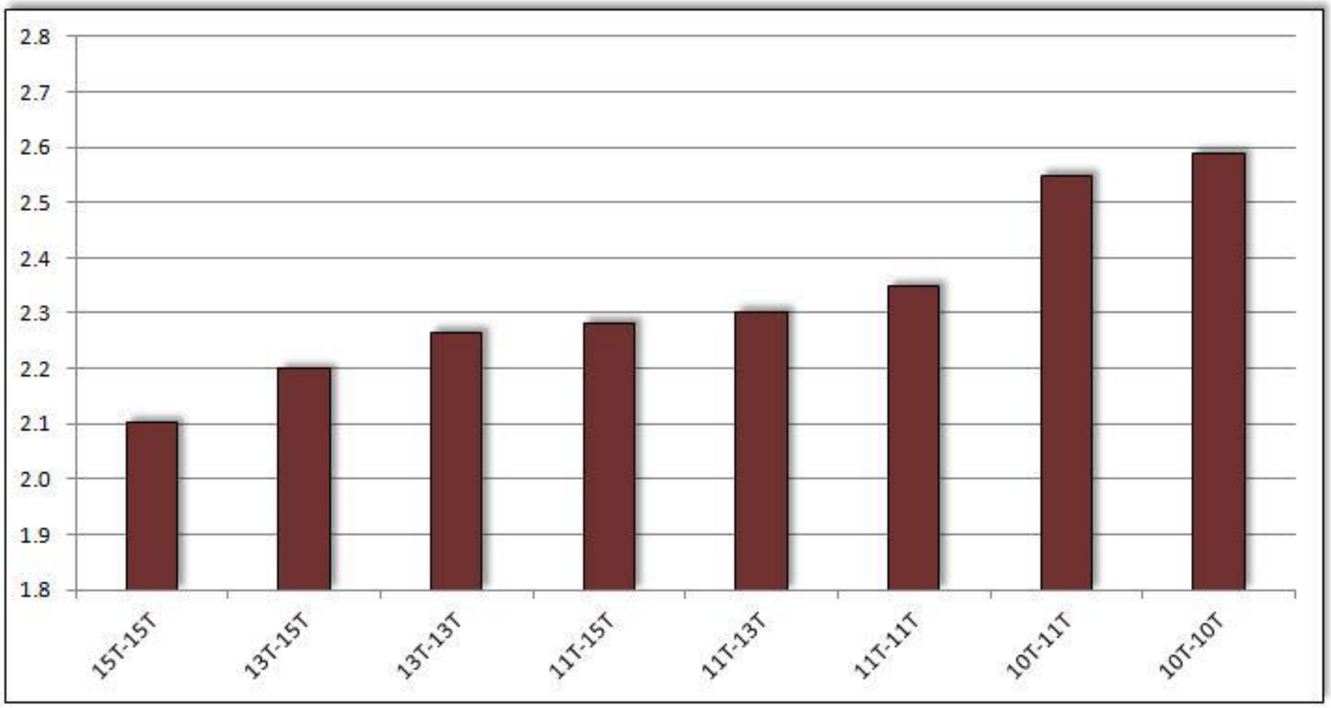


Graph 1: Frictional Losses in watts of each pulley combination for Parts 1, 2, and 3.

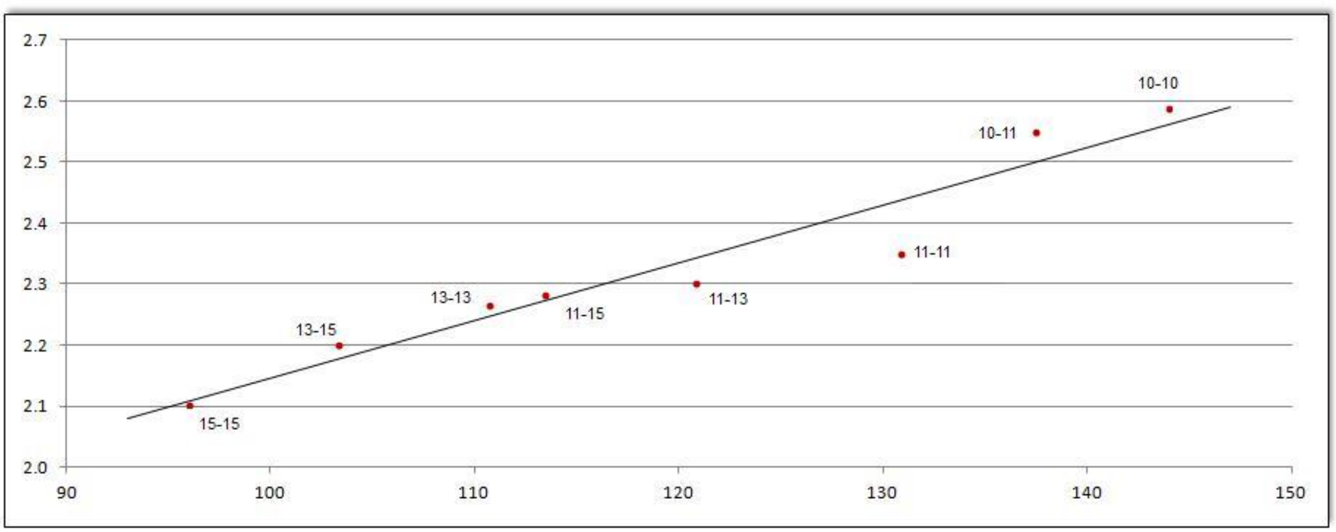
RESULTS

Part 1:

Generic plastic pulley wheels tested to validate the theory. Chain tension held constant at 2.4lb per span. Bearings held constant. The same two ceramic bearings were used for each of the eight pulley combinations. Plastic 10T, 11T, 13T, and 15T wheels used for Part 1.



Graph 2: Frictional Losses (watts) vs. Pulley Size Combination. Chain tension and bearings held constant.

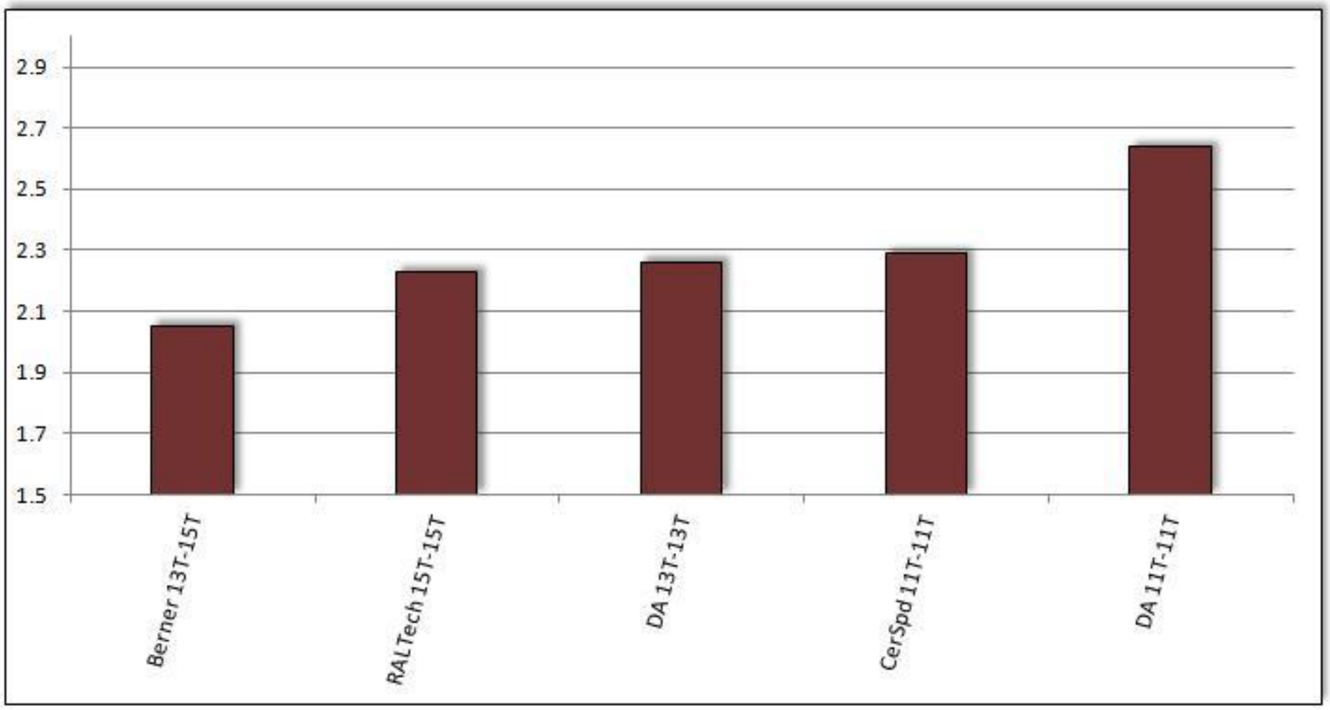


Graph 3: Frictional Losses (watts) vs Total Chain Articulation Angle. A linear trend line was superimposed. Chain

tension and bearings held constant. Total Chain Articulation Angle is the sum of the engagement and disengagement angles for both upper and lower pulleys. For example, a 10T-10T combination is 36° engagement plus 36° disengagement times two 10T pulleys equals 144°.

Pic 1: Shimano Acera and 105 plastic wheels with inner diameters identically milled to accept the two TACX ceramic bearings. L to R:
TACX bearings, 10T, 11T, 13T, 15T.

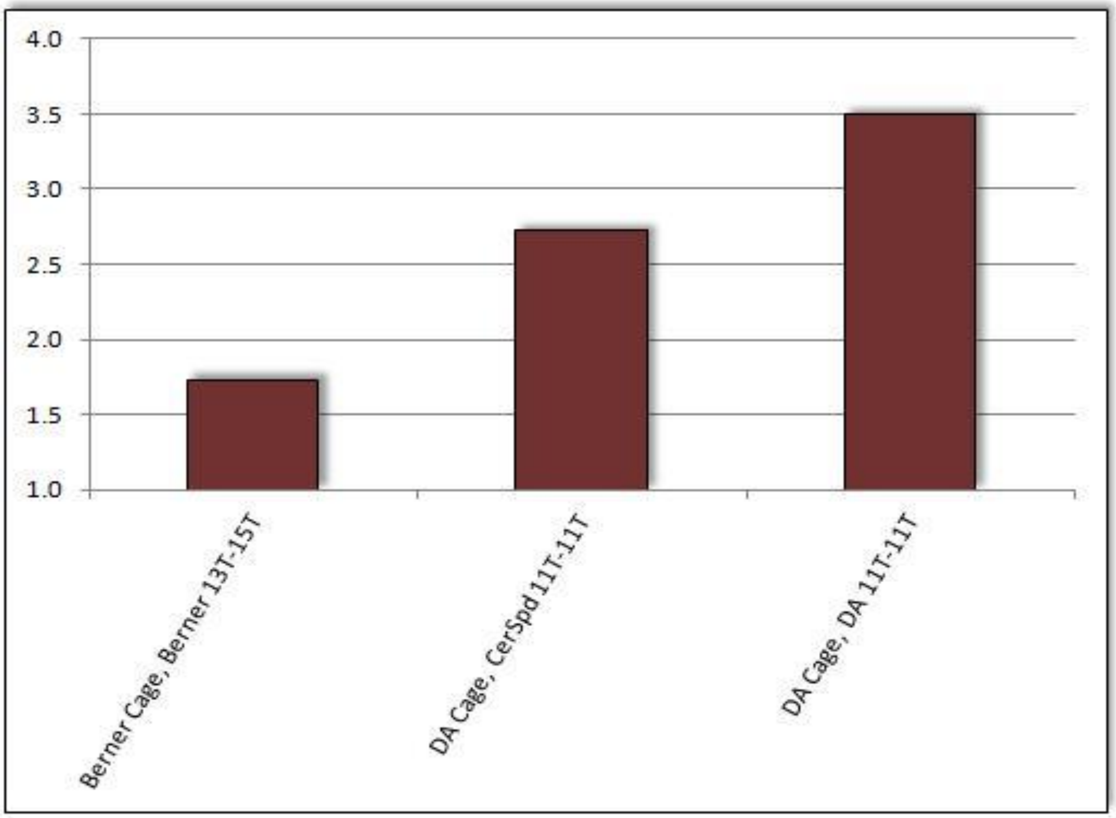
Part 2:
Commercially available pulleys tested with the manufacturers' provided bearings. Chain tension was held constant in the same manner as Part 1 (manufacturers' cages not used). Bearing variable introduced to the Part 2 test sequence.



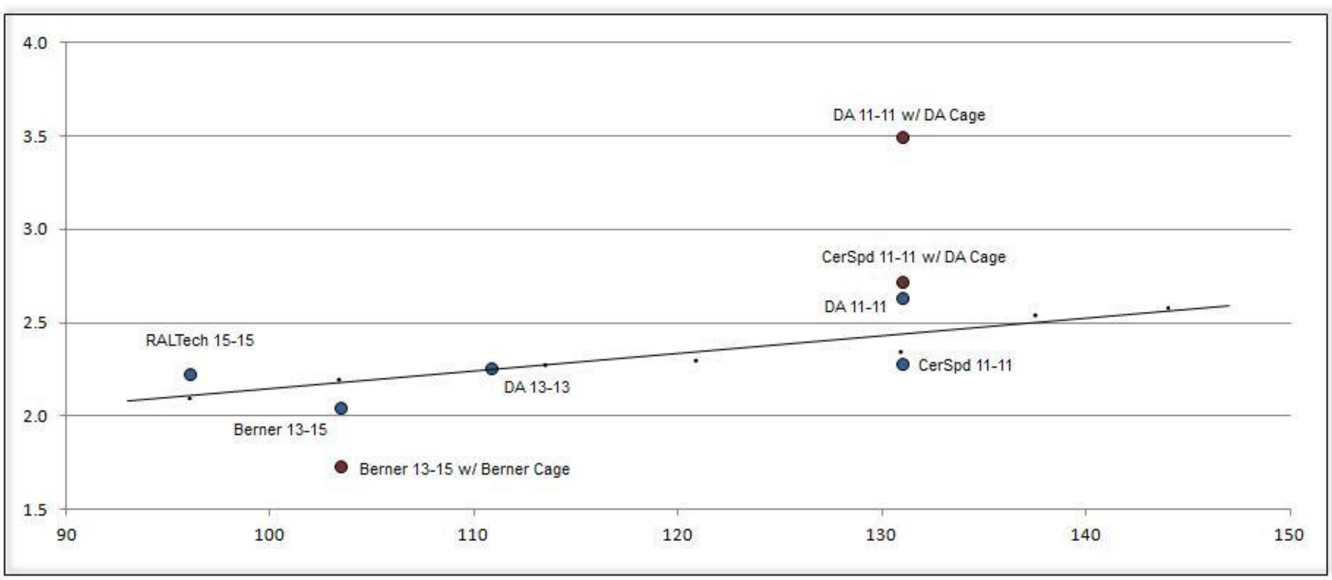
Graph 3: Frictional Losses (watts) vs. Pulley Size Combination. Chain Tension was held constant. Bearing variable was introduced.

Pic 2: Oversized pulleys used for Part 2. L to R, Dura Ace 13T-13T, Berner 13T-15T, RALTech 15T-15T.

Part 3:
Commercially available pulleys tested with the manufacturers' provided bearings and derailleur cage. Both chain tension and bearing variables were present in Part 3.



Graph 4: Frictional Losses (watts) vs. Pulley Size Combination. Manufacturers' cages and Bearings were included in the test sequence.



Graph 5: Frictional losses (watts) vs. Pulley System. The data from Parts 2 and 3 were superimposed onto the trend line from Part 1. Blue markers indicate Part 2 data. Red markers indicate Part 3 data.

Background:

In a derailleur-style drivetrain, friction is created as the chain moves through the derailleur pulleys. This friction is due to several factors. The major contributing factors to the derailleur system's frictional losses are as follows:

1) Angle of chain articulation as the chain engages and disengages the pulleys. Large articulation angles increase friction.
2) Number of articulations per unit time. I.e., how many chain links engage (or disengage) the pulley per unit time. Higher numbers of articulations per unit time increase friction.
3) Tension of the chain in the bottom spans created by the spring-loaded derailleur cage. Higher chain tension increases friction.
4) General efficiency of the pulley bearings (regardless of bearing speed). Less efficient bearings increase friction.
5) Speed of the bearings in the pulleys. Higher bearing RPM increases friction.

When analyzing the frictional effects of a larger pulley from a theoretical standpoint, a larger pulley will decrease the friction based on factors (1) and (5) listed above. Larger pulleys inherently have lower articulation angles, decreasing friction. Additionally, a larger pulley spins more slowly for a given cadence and ring, decreasing the rotational speed of the bearing, thereby lowering the friction. Part 1 of this test analyzes the effects of factors (1) and (5)

Additionally, the friction of the derailleur pulley 'system' can be affected by factors (3) and (4) above. A 'system' is defined as the pulleys, the pulley bearings, and the derailleur cage. These factors must be considered as the frictional losses due to inefficient bearings and/or increased chain tension applied by the cage could offset the efficiency gains due to the use of an oversized pulley. Due to these contributing factors, Part 2 analyzes the effects of bearings and Part 3 analyzes the effects of the derailleur cage on total friction. By segregating the frictional gains and losses of each contributing factor, the pulley system as a whole can be better understood.

(On a side note, factor (2), articulation rate, is held constant through all parts of this test, at 95RPM cadence with a 53T front ring. If rider cadence is held constant (and ring size is constant), articulation rate (chain speed) will not vary whether using a large or small pulley. As such, the effects of cadence on derailleur friction is not explored in this test.

Part 1: Confirming the "Bigger is Better" Theory

Test Method: Part 1 of the test analyzes the effects of chain articulation angle and bearing speed on total friction, i.e., looking at the 'theoretical" gains of using oversized pulleys. To eliminate the variable of chain tension, the equipment was set up to provide identical chain tension for each pulley combination, which was 2.4lbs. To eliminate variables due to different bearings, two ceramic bearings were utilized and swapped into and out of the different sized pulley wheels for each combination in Part 1. Each of the pulley wheels had their respective inside diameters identically milled to match the outside diameters of the two bearings. 'Generic' plastic wheels sized from 10T to 15T were used. Three chains were used for each individual test combination for all parts of this test.

Results: The data shows that friction decreases in a linear manner with increasing pulley diameter, when plotted as watts vs. total angle of articulation. The experimental results agree with the oversized pulley theory regarding efficiency increases with larger diameter pulleys. The data shows a difference of 0.49 watts between the smallest diameter pulley combination (10T-10T) and the largest diameter pulley combination (15T-15T), with bearings and chain tension held constant.

Part 2: Effects of Bearings

Test Method: Using the same constant-tension (2.4lbs) equipment set up as Part 1, Part 2 analyzed three commercially available pulleys with the manufacturer-provided bearings instead of the 'generic' wheels with the same bearings. Dura Ace 13T-13T, Berner 13T-15T (ceramic model), and RALTech 15T-15T pulleys were tested. This test method effectively analyzes the effects of the bearings when the results of each pulley combination of Part 2 are compared to the linear trend line from Part 1. Additionally, two 11T non-oversized pulleys were included in Part 2 for comparison purposes. Namely, Dura Ace 11T-11T (RD-9000), and CeramicSpeed 11T-11T pulleys. The DA 11T-11T combination was chosen as this is a very common combination, and the CeramicSpeed pulleys were chosen as they were the top performing 11T-11T pulley set from the previously-performed "Derailleur Pulley Efficiency Test" which analyzed 17 models of 11T-11T pulleys.

Results: Graph 5 shows the five models of pulleys compared to the corresponding generic pulleys and the linear trend line. The five models are indicated with the blue marker dots.

Moving from left to right on the graph (larger pulleys to smaller), the RALTech 15T-15T pulleys exhibited higher friction than the generic 15T-15T with ceramic bearings. This is most likely due to less efficient bearings provided with the RALTech Pulleys.

The Berner 13T-15T exhibited less friction than their generic 13T-15T counterparts. This is most likely due to the high efficiency ceramic bearings provided with the pulley by the manufacturer (CeramicSpeed ceramic bearings according to the Berner specs). It is interesting to note that the Berner 13T-15T, even though at a disadvantage when considering the total articulation angle, demonstrated less friction than the RALTech 15T-15T. This is most likely an example of lower efficiency bearings offsetting the advantage of a larger total articulation angle, when comparing the Berner 13T-15T to the RALTech 15T-15T. I.e., the largest pulleys (in this case a 15T-15T combination), while having the advantage of an oversized design, don't always equate to the most efficient complete pulley system.

The DA 13T-13T pulleys exhibited a friction level within 0.01 watts of the generic 13T-13T. This is most likely due to the DA 13T ceramic bearings being similar in efficiency to the TACX ceramic bearings used in the generic pulleys. To support this observation, the single-row DA 11T and TACX 11T pulleys exhibited friction within 0.01 watts of each other when tested in the previously-performed "Derailleur Pulley Efficiency Test".

The CeramicSpeed 11T-11T pulleys exhibited lower friction than the generic 11T-11T. Conversely, the DA 11T-11T pulleys exhibited higher friction than the generic 11T-11T. Additionally, these two set of pulleys exhibited the highest differences (CeramicSpeed lower and DA higher) of all five test sets when compared to their generic pulley counterparts, and a difference of 0.35 watts when compared to each other. Again, this is most likely due to the bearing efficiency within each model.

Part 3: Effects of Chain Tension due to the Pulley Cage

Test Method: Part 3 of this test introduces the variable of chain tension. For Parts 1 and 2, a constant span tension of 2.4 lbs was applied. For Part 3, the tension was governed by the effects of each of two spring-loaded pulley cages, the Berner cage and the DA RD-9000 cage. As discussed above, the tension applied to the chain by the cage can affect the friction of the system. Higher tension equates to higher friction levels. A Dura Ace cage with Dura Ace 11T-11T pulleys, a Dura Ace cage with CeramicSpeed 11T-11T pulleys, and a Berner Cage with Berner 13T-15T pulleys were tested in Part 3.

Results: As seen in Graph 5, the Berner cage/Berner pulley system exhibited the lowest friction of any combination tested of all three parts of the test. Conversely, the DA cage/DA pulley system exhibited the highest friction level of any combination tested of all three parts of this test. Each of the respective systems described above exhibited outlying friction levels when compared to the same systems pulleys' levels from Part 2. This is due to the differences in chain tension created by the different cages. The Berner cage creates a chain tension of 1.54lbs. The DA cage creates a chain tension of 3.19lbs.

The Berner cage creates lower chain tension by taking advantage of basic geometric lever-arm principles and also by using a unique design feature. The geometric advantage is based on the extended length of the cage itself (when compared to the length of a standard short cage, as seen with the DA cage) plus the added radius of the 15T lower pulley. Both of these extensions effectively create a cage with a longer lever arm thereby decreasing the effective tension placed on the chain.

Additionally, the Berner cage utilizes a novel design feature of offsetting the attachment point of the derailleur cage torsion spring by approximately 60° (Pic 3). This offset decreases the torque applied by the torsion spring to the cage thereby decreasing the effective tension placed on the chain, and is additive to the decrease in tension due to the longer lever arm.

Pic 3: Red arrows indicate the different angular attachment points of the torsion spring to the cage.

Part 3 results of the complete derailleur systems could be considered the most valuable 'real world' data as this part of the test includes all variables found in commercially available cage/pulley/bearing systems.

This test was performed in clean laboratory conditions, with pristine test chains and lubricants. In ‘real world’ conditions, the chain and chain lube would most likely be contaminated to some degree, increasing the frictional contribution of the chain to the equation. Therefore, the wattage savings would most likely be even greater in ‘real world’ than seen in the lab. It is speculated that upwards of two watts could be saved during clean road racing conditions.

Possible disadvantages of the oversized pulley system include the additional weight of additional chain links needed to accommodate the larger pulleys, plus the additional aerodynamic resistance due to the larger cage.

DATA:

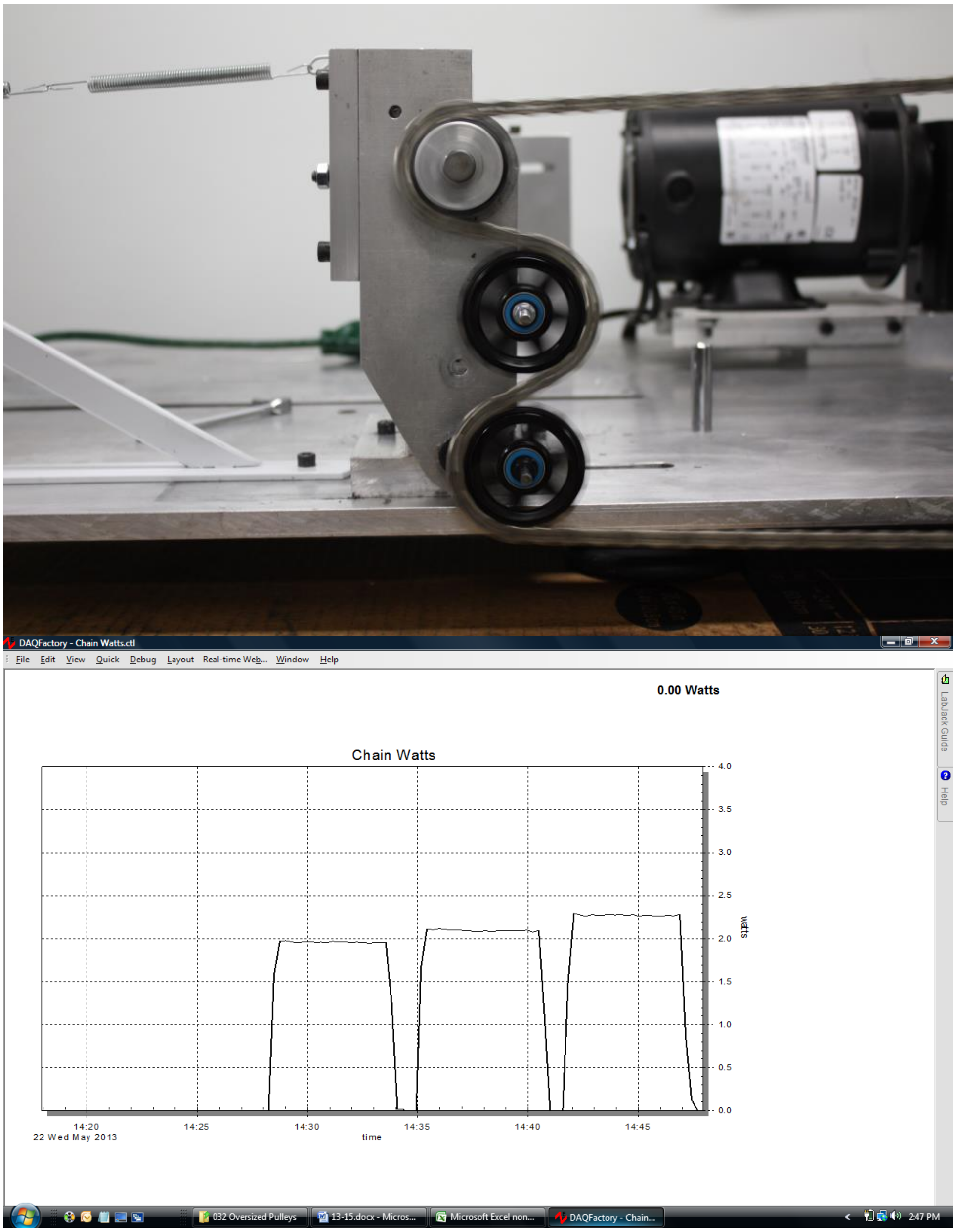
Pulley Combination	Chain					
	Campy	Shimano	SRAM	**Average (watts)**	Total Articulation Angle	Tension (lb)
PART 1						
15T-15T	1.95	2.09	2.27	**2.10**	96.00	2.40
13T-15T	2.03	2.20	2.37	**2.20**	103.38	2.40
13T-13T	2.10	2.28	2.42	**2.27**	110.77	2.40
11T-15T	2.14	2.26	2.45	**2.28**	113.45	2.40
11T-13T	2.14	2.30	2.47	**2.30**	120.84	2.40
11T-11T	2.19	2.35	2.51	**2.35**	130.91	2.40
10T-11T	2.44	2.51	2.70	**2.55**	137.45	2.40
10T-10T	2.49	2.55	2.73	**2.59**	144.00	2.40
PART 2						
Berner 13T-15T	1.94	2.01	2.21	**2.05**	103.38	2.40
RALTech 15T-15T	2.14	2.19	2.36	**2.23**	96.00	2.40
DA 13T-13T	2.08	2.30	2.41	**2.26**	110.77	2.40
CerSpd 11T-11T	2.16	2.24	2.47	**2.29**	130.91	2.40
DA 11T-11T	2.50	2.60	2.82	**2.64**	130.91	2.40
PART 3						
Berner Cage, Berner 13T-15T	1.58	1.78	1.85	**1.74**	103.38	1.54
DA Cage, CerSpd 11T-11T	2.55	2.64	2.98	**2.72**	130.91	3.19
DA Cage, DA 11T-11T	3.26	3.49	3.75	**3.50**	130.91	3.19

ADDITIONAL TEST METHOD NOTES:

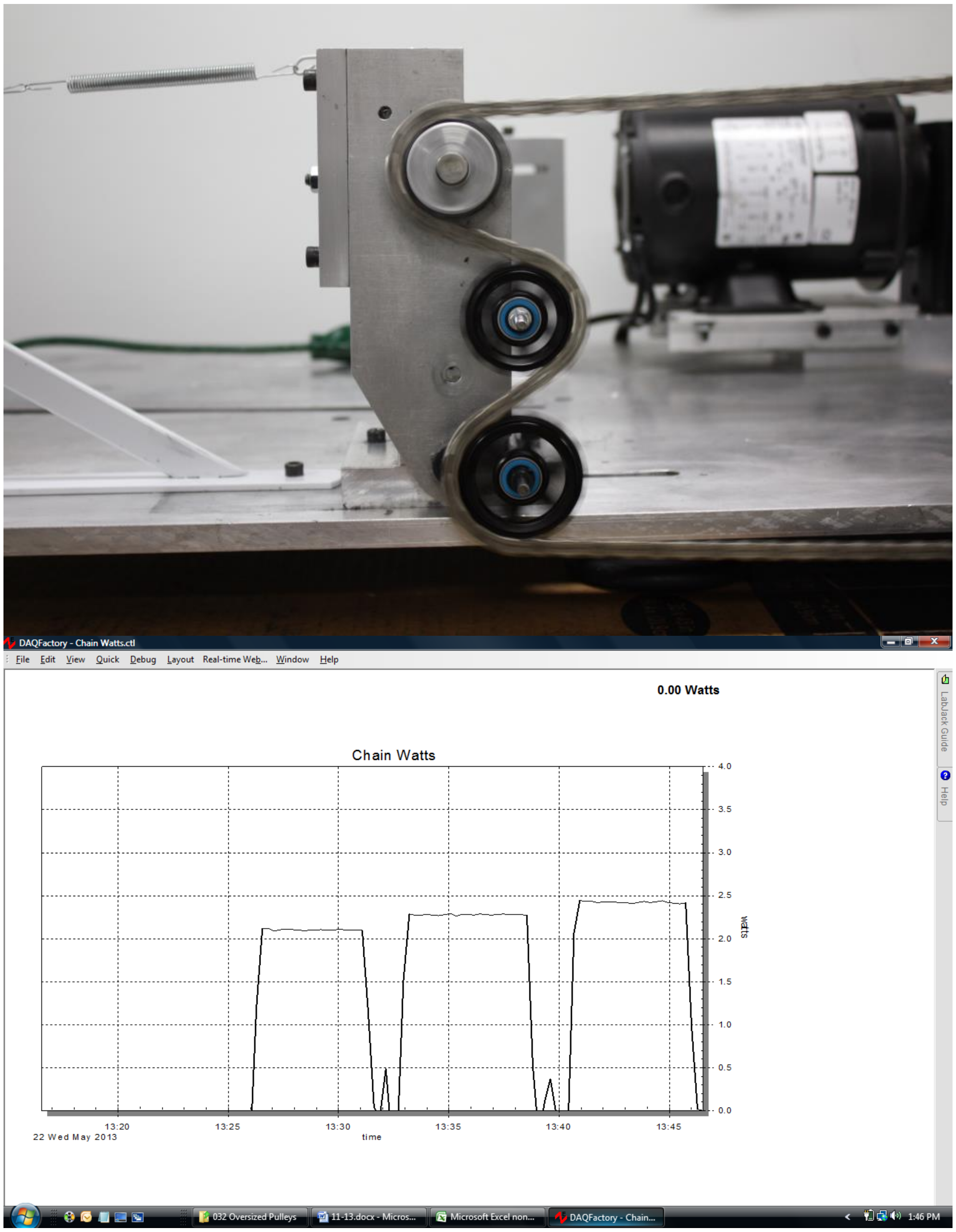
- Three 10sp chains were used to test the friction of each pulley combination. The chains were a Shimano CN-7901 (DA), SRAM PC1091R (Red), and a Campagnolo Record UltraNarrow 10. This was done to eliminate any variables due to a specific model of chain, as well as increase the statistical significance of the data.
- Each chain was broken-in for 6 hours at 250 watts on the Full Load Tester, ultrasonically cleaned, and ultrasonically re-lubed with AGS light bearing oil. This break-in at full load minimizes the chains' contribution of friction variables during the test at low tensions.
- Each chain was tested with the same side facing out throughout the test sequence.
- The TACX bearings were broken in for two hours.

- When a combination of two different sized pulleys was tested, the smaller of the two pulleys was always placed in the upper position.
- The ‘generic’ pulley wheels were Shimano 105 and Acera wheels. These wheels were chosen due to the ease of machining and low cost (with regard to the test budget).
- This test was performed with the pulleys, ring, and cog in a purely coplanar position (no cross chaining). Prior to each combination being tested, the pulleys were aligned to ensure proper coplanar positioning.
- For Parts 1 and 2, the constant chain tension of 2.4lbs was chosen based on the average tension applied by a long style cage with an 11T lower pulley.
- For Parts 1 and 2, the equipment was set up to allow adjustment of chain span lengths, while maintaining a constant 2.4lbs. I.e., the adjustment of chain span length to accommodate different pulleys size did not affect chain tension.
- For Part 3, the top chain span length was fixed (equipment locked), allowing the cage to float and provide the chain tension. However, the top span length was adjusted prior to locking for each of the two cages in order to place each of the two cages in a vertical orientation.
- Chain Articulation Angle was used for the X-axis in the line graphs as this is the linear dependent factor of pulley diameter, as opposed to using tooth count for the X-axis. Tooth count does not correspond linearly to the inverse of articulation angle. For example, if an 11-15 combination was compared to a 13-13 combination, the total tooth count would be the same and each pulley would be located at the same point along the x-axis of the line graph if plotting teeth count vs. watts. However, this is not accurate. The total articulation angle of the 11-15 combination is 113.45°, whereas the total articulation angle of the 13-13 is 110.77°. Because of this relationship, *total articulation angle* must be plotted against watts, not *tooth count* vs. watts.
- In addition to increased chain weight and aerodynamic effects, a possible efficiency disadvantage of an oversized pulley system could be friction created by increased lateral moment on the lower pulley created during heavy cross-chaining. This has not been tested, but can be calculated. A simple calculation shows this increased friction would be under 0.01 watts at the maximum cross-chain condition, and decreases to 0.0 watts at a straight-chain-line condition. Worst case scenario calcs: With 2.4lbs at a 10deg angle, this is an approximate lateral load of 0.4 lbs, applied at the edge of the lower pulley. Both small and large pulleys would be subjected to the same lateral loading of 0.4 lbs, however, the moment of the 15T vs 11T is increased by 36%. Knowing the friction of most ceramic pulley bearings is up to 0.05 watts per pulley with 4.4lbs of radial loading, an addition of 0.4 lbs lateral load would most likely increase friction of no more than 0.02 watts. The difference between large and small pulley friction due to the cross-chain lateral load would be 0.02 watts * 36%, or 0.072 watts.
- Crank cadence was 95RPM
- A 53T front ring and 12T rear cog was used.
- The Tension Test Method was used for measurement. Accuracy of this tester is +/- 0.02 watts. Additional details can be found at:
http://www.friction-facts.com/equipment/full-tension-test-method
- Equipment system losses were removed prior to the data presented in this report.
- Data was recorded at the end of each chain’s 5 minute run with the given pulley combination.

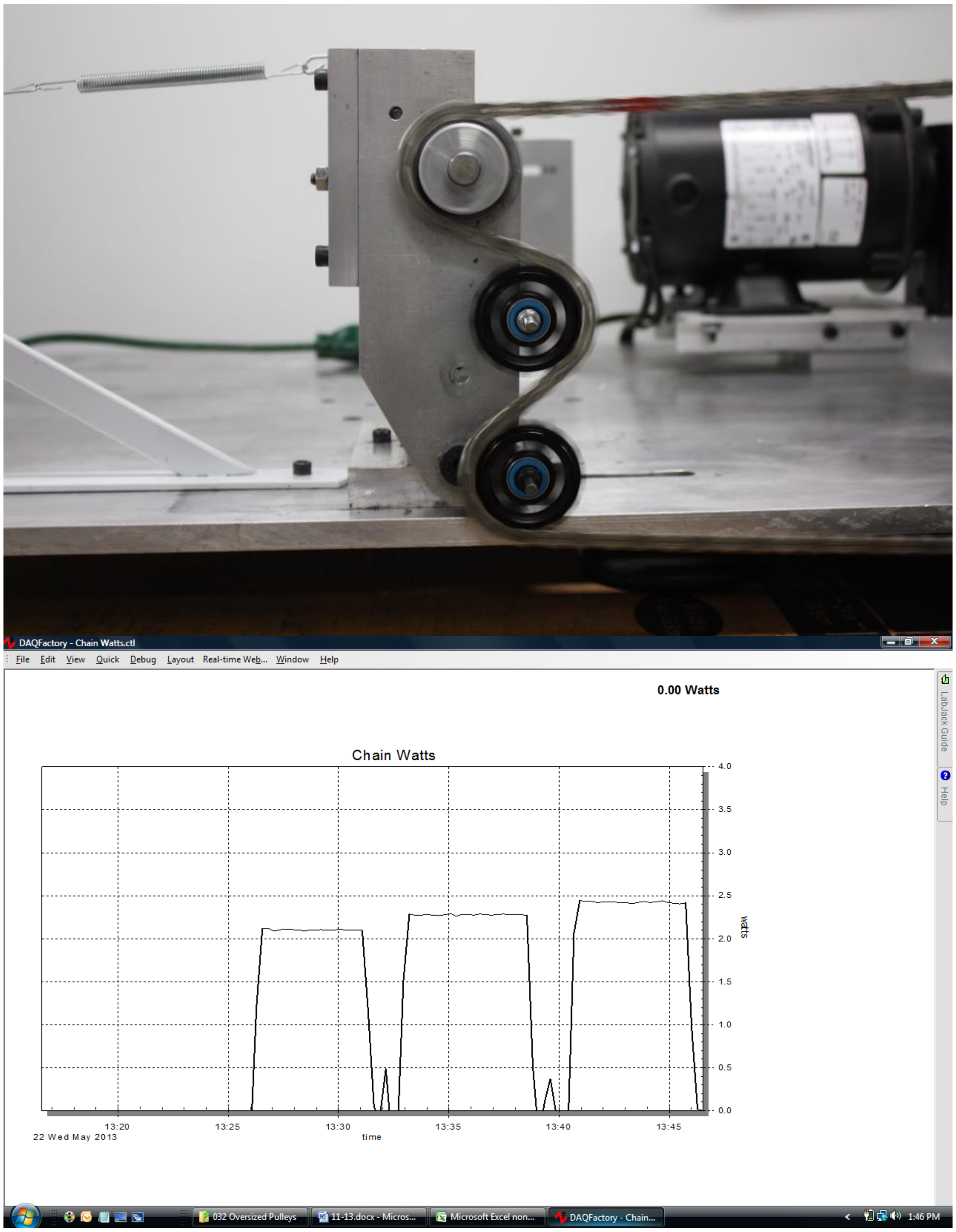
SCREEN CAPTURES AND PICTURES OF EACH COMBINATION:



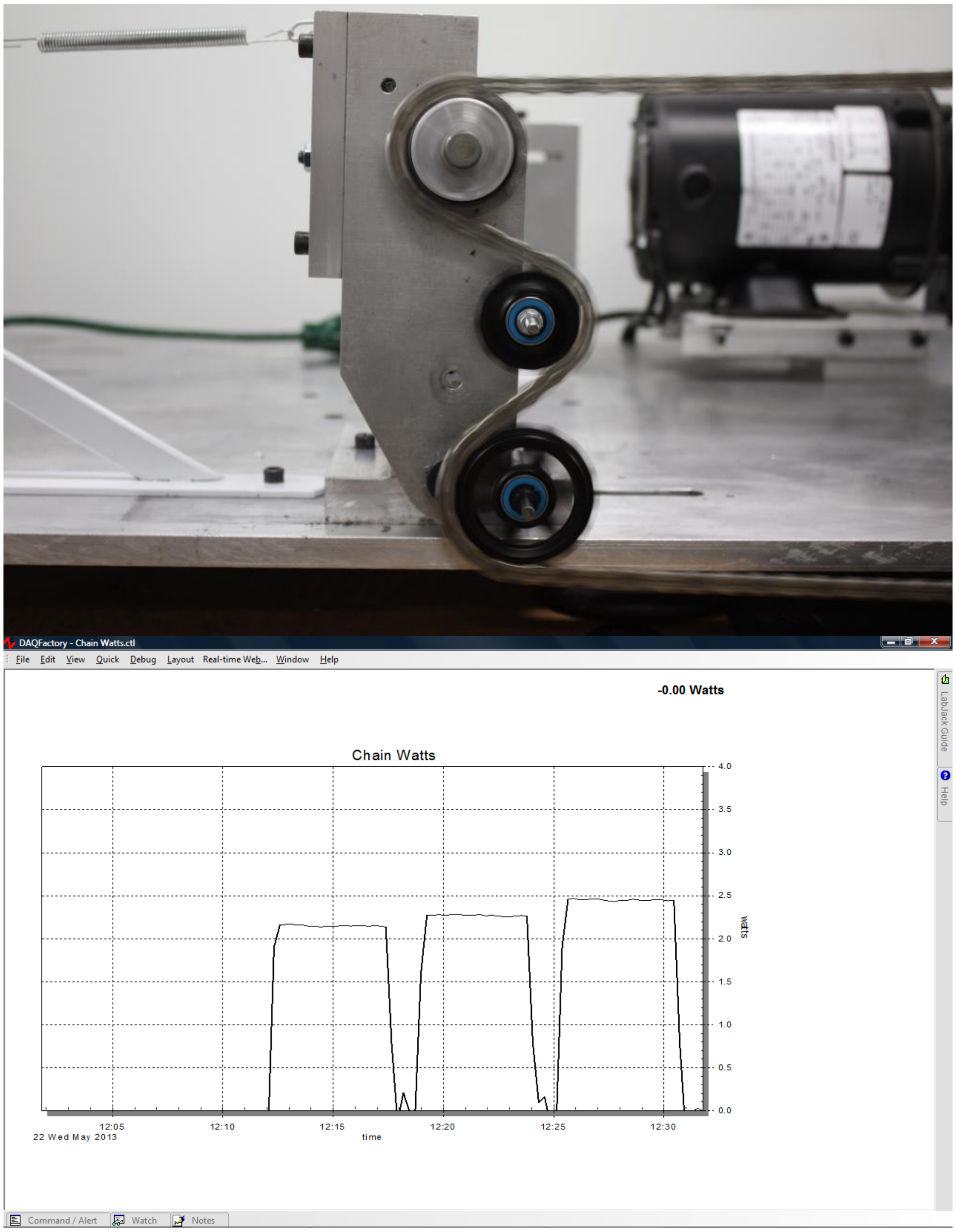
15T-15T Combination.
All chains tested in the following order for each combination:
Campagnolo, Shimano, SRAM. The peaks represent this order.



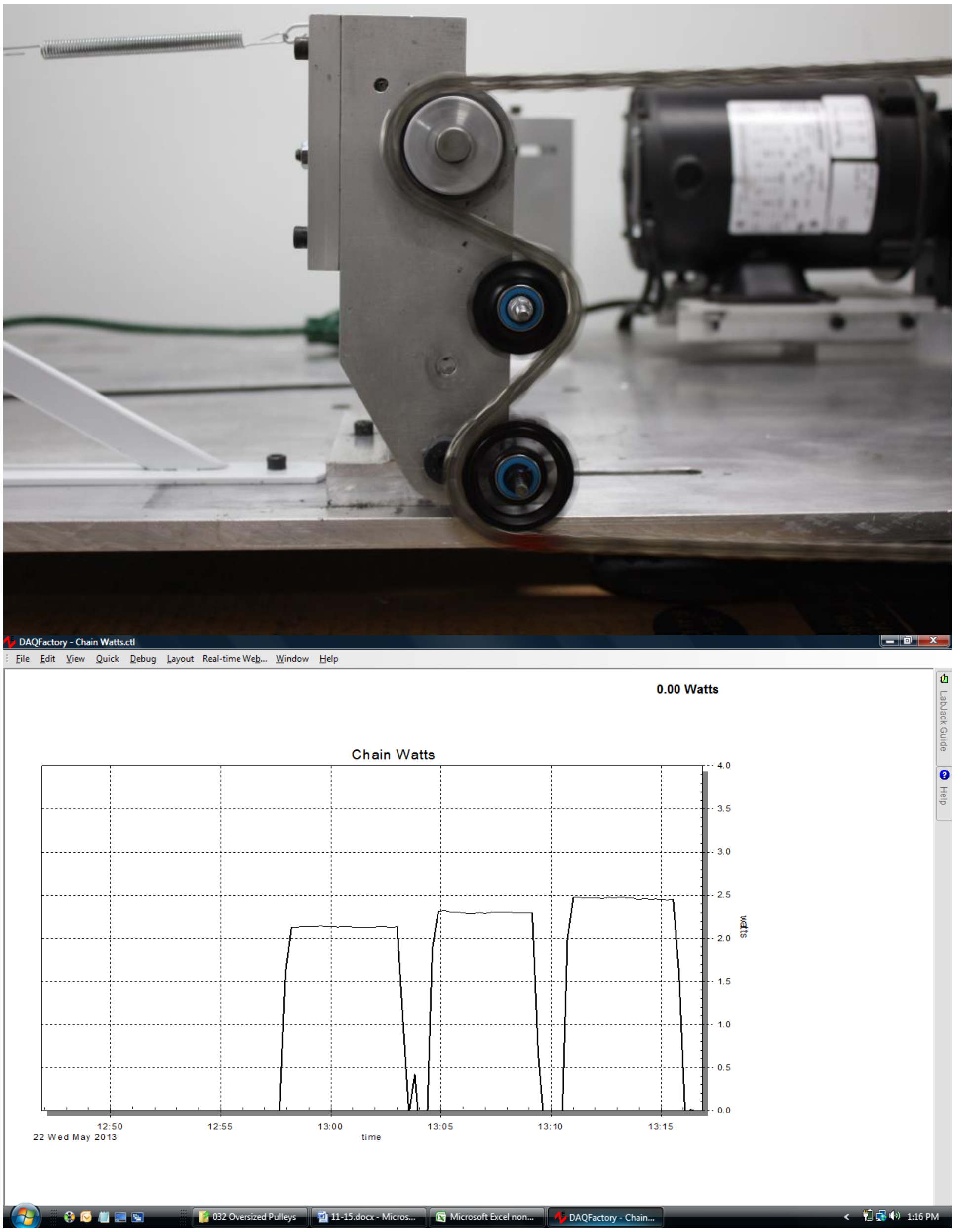
13T-15T Combination.



13T-13T Combination.



11T-15T Combination.



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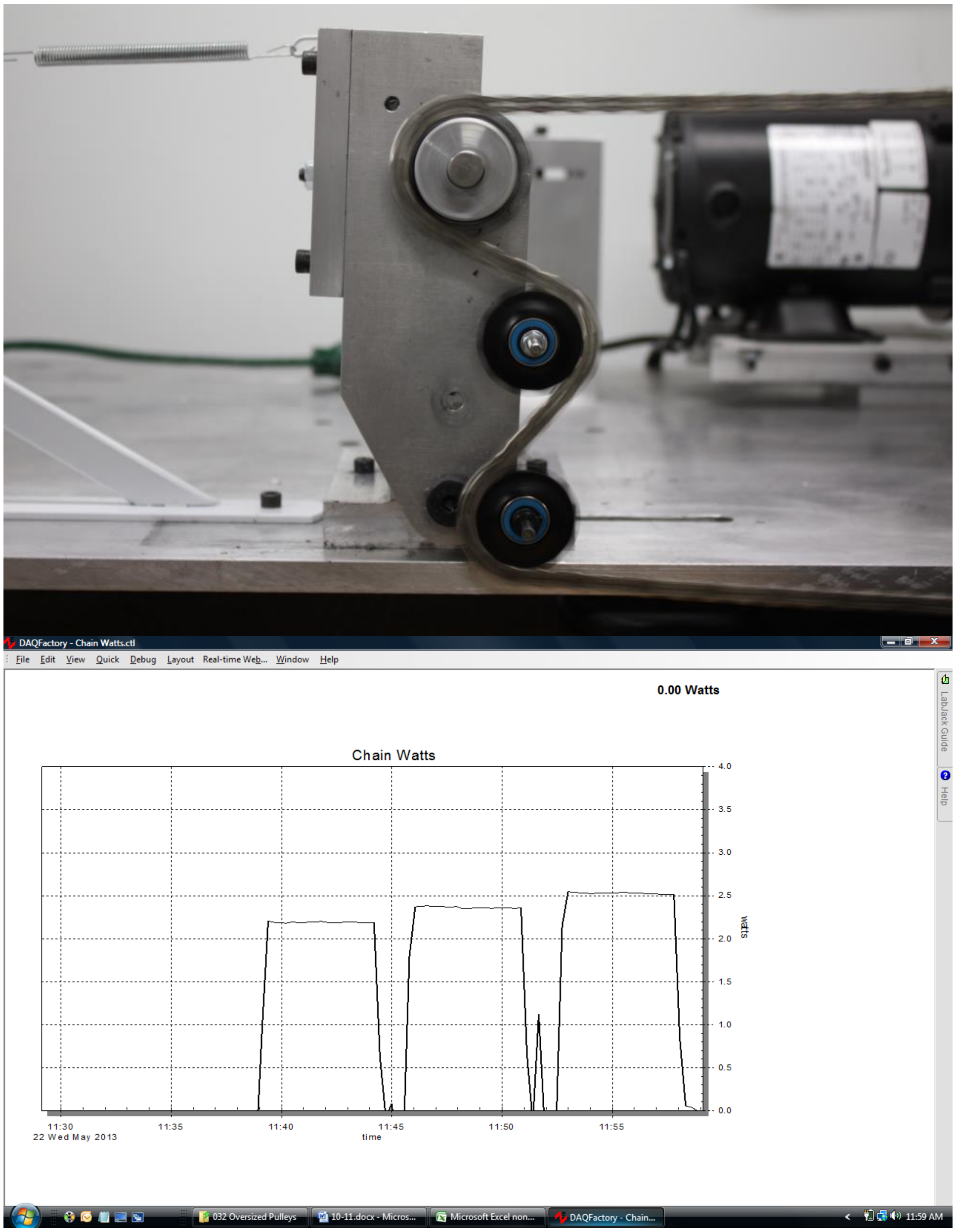

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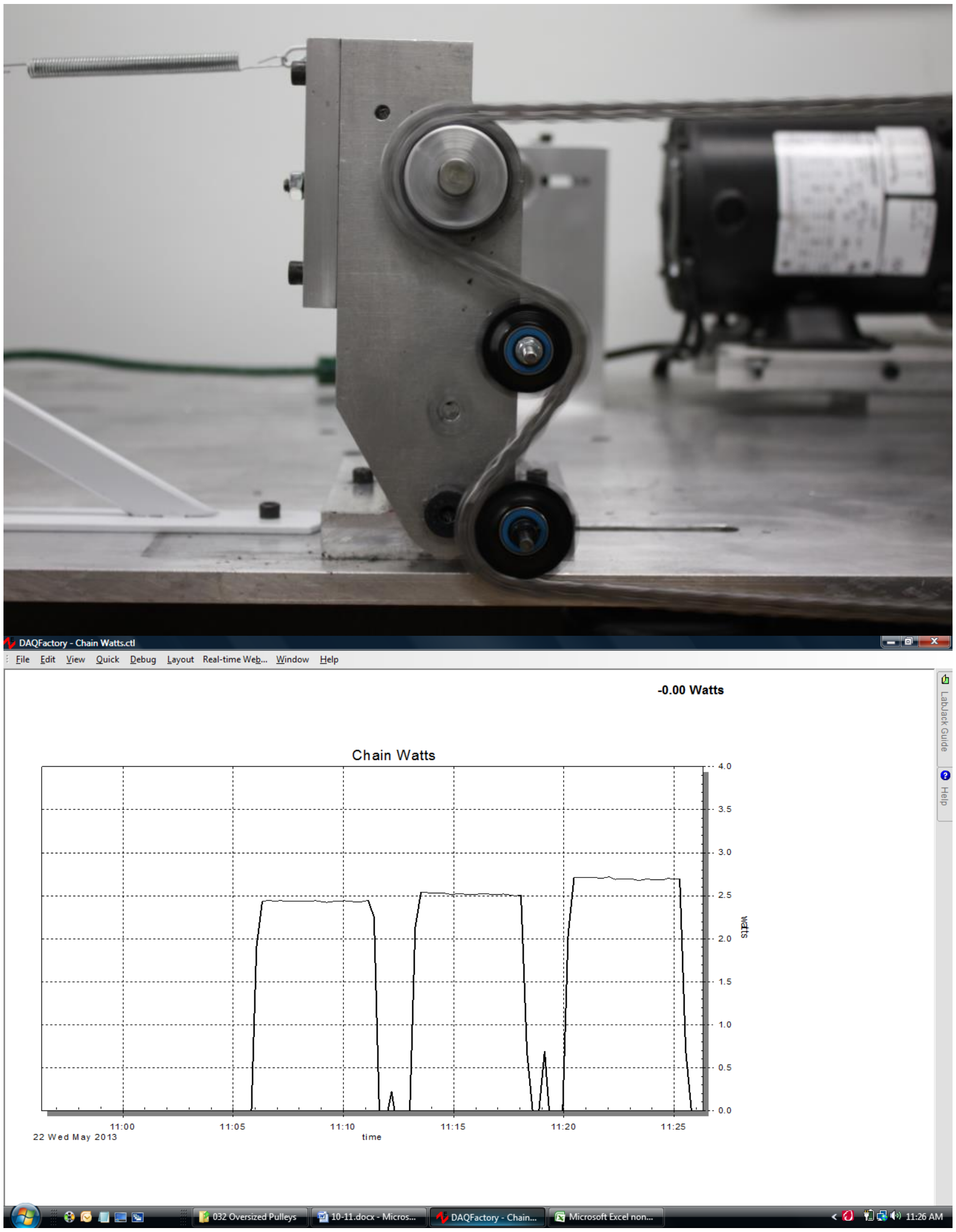
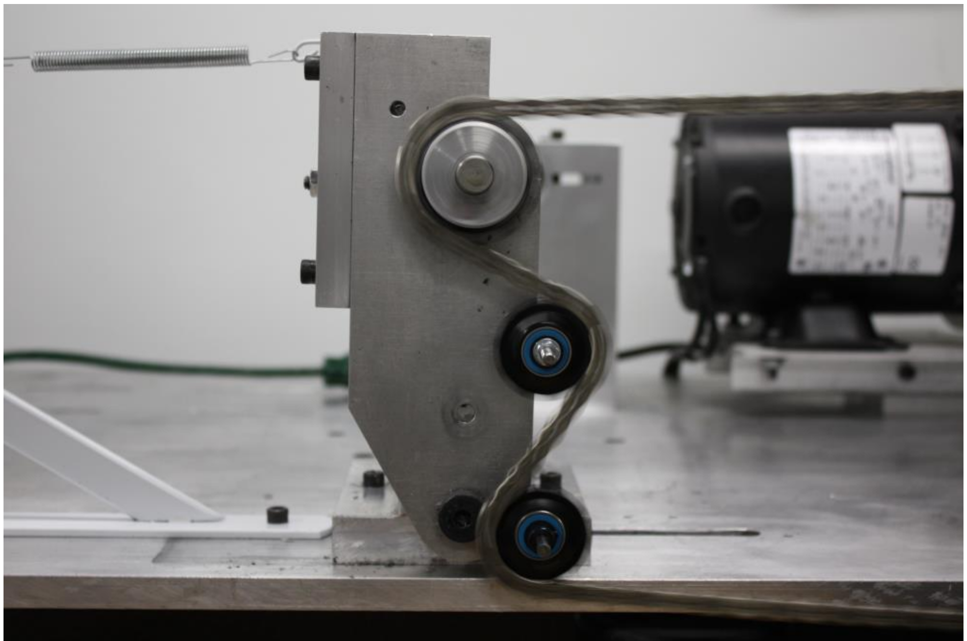
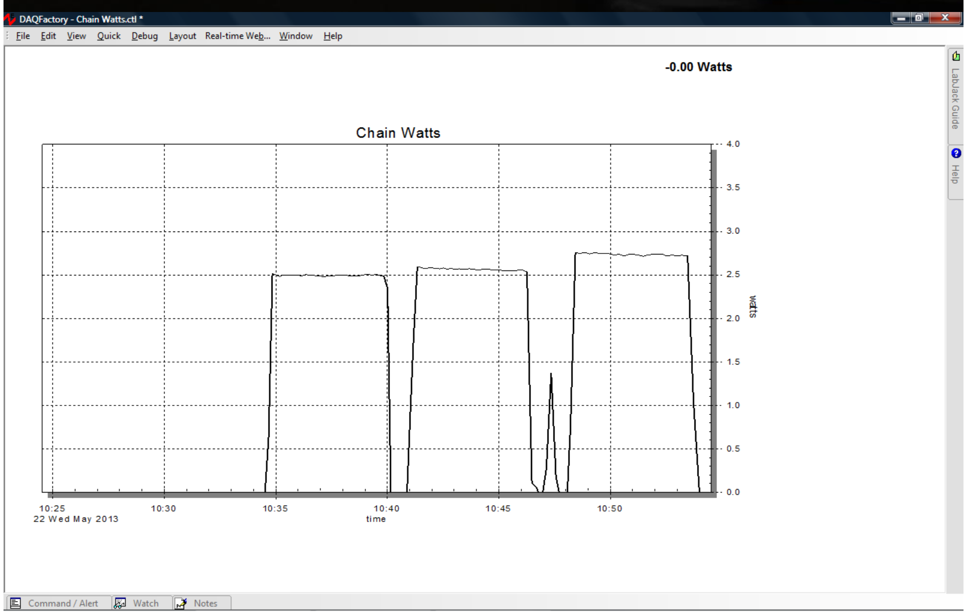
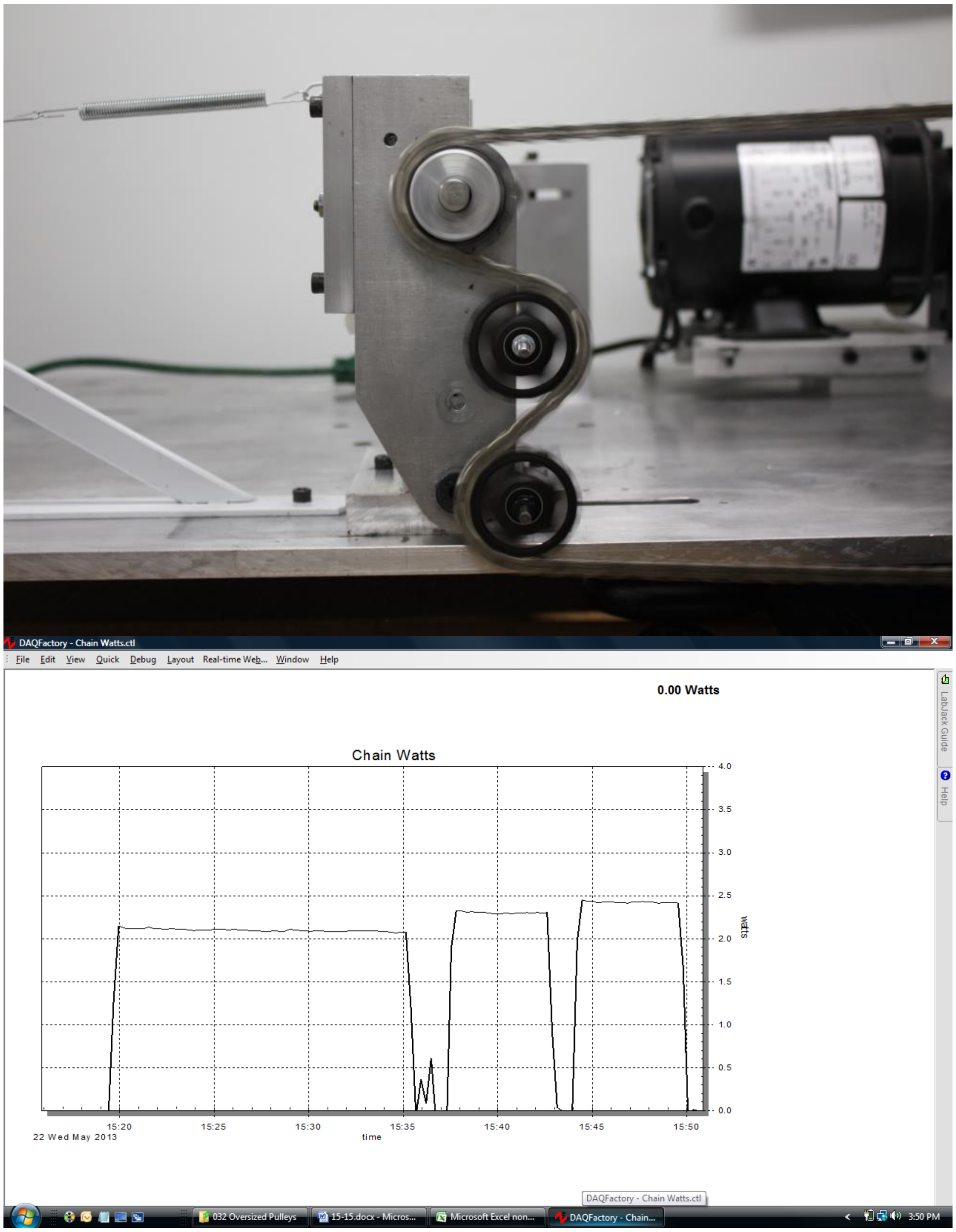


10T-11T Combination.

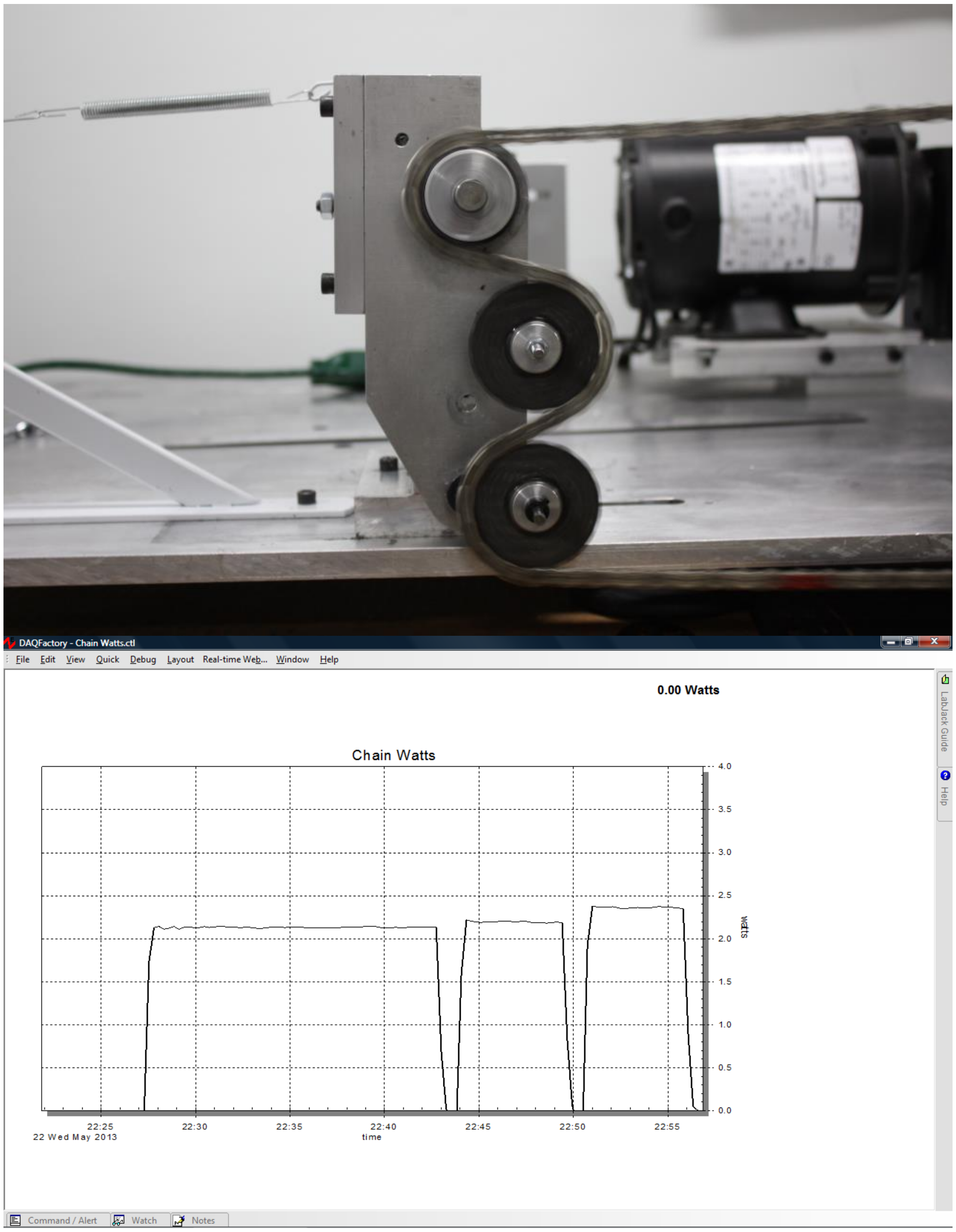




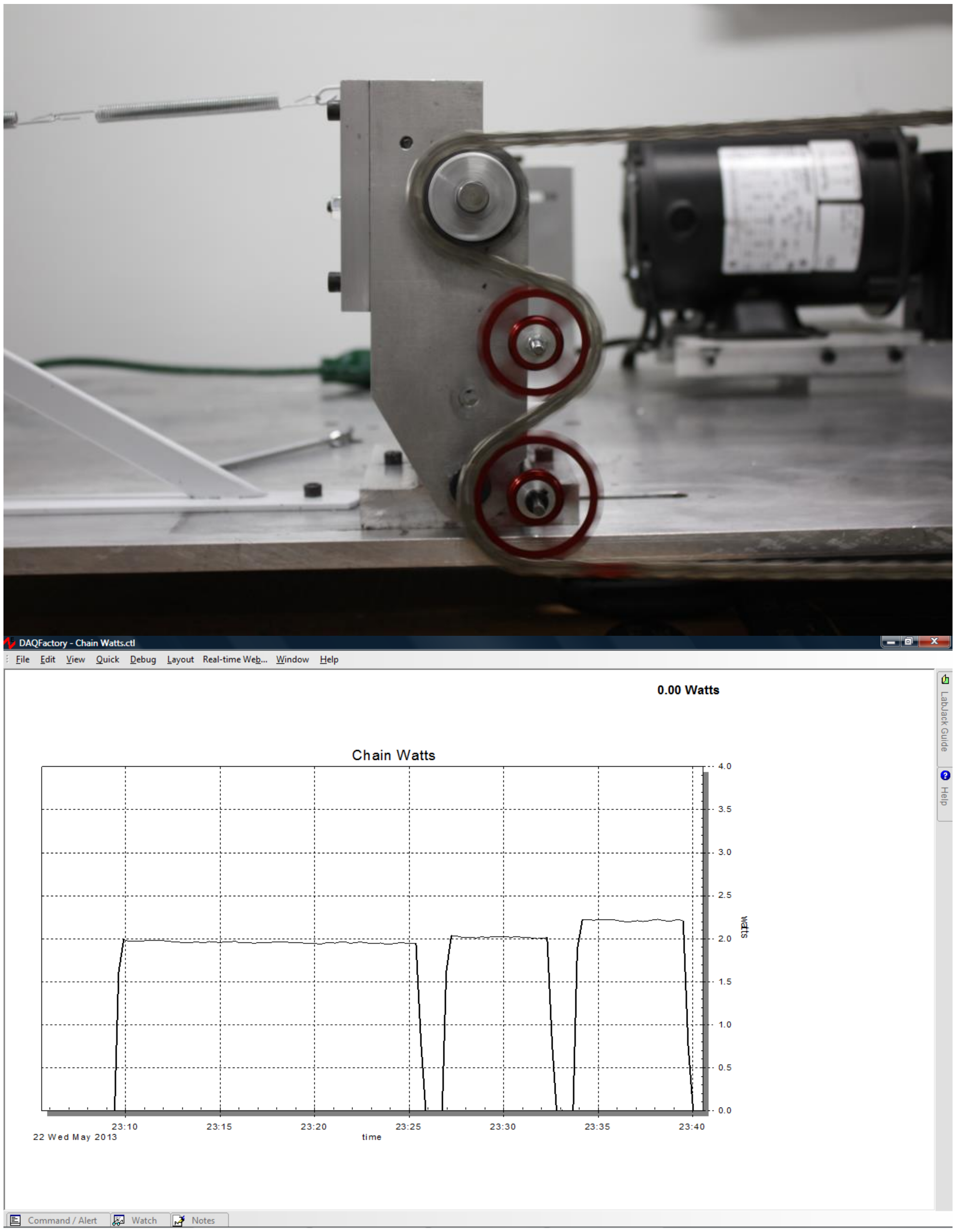
10T-10T Combination.



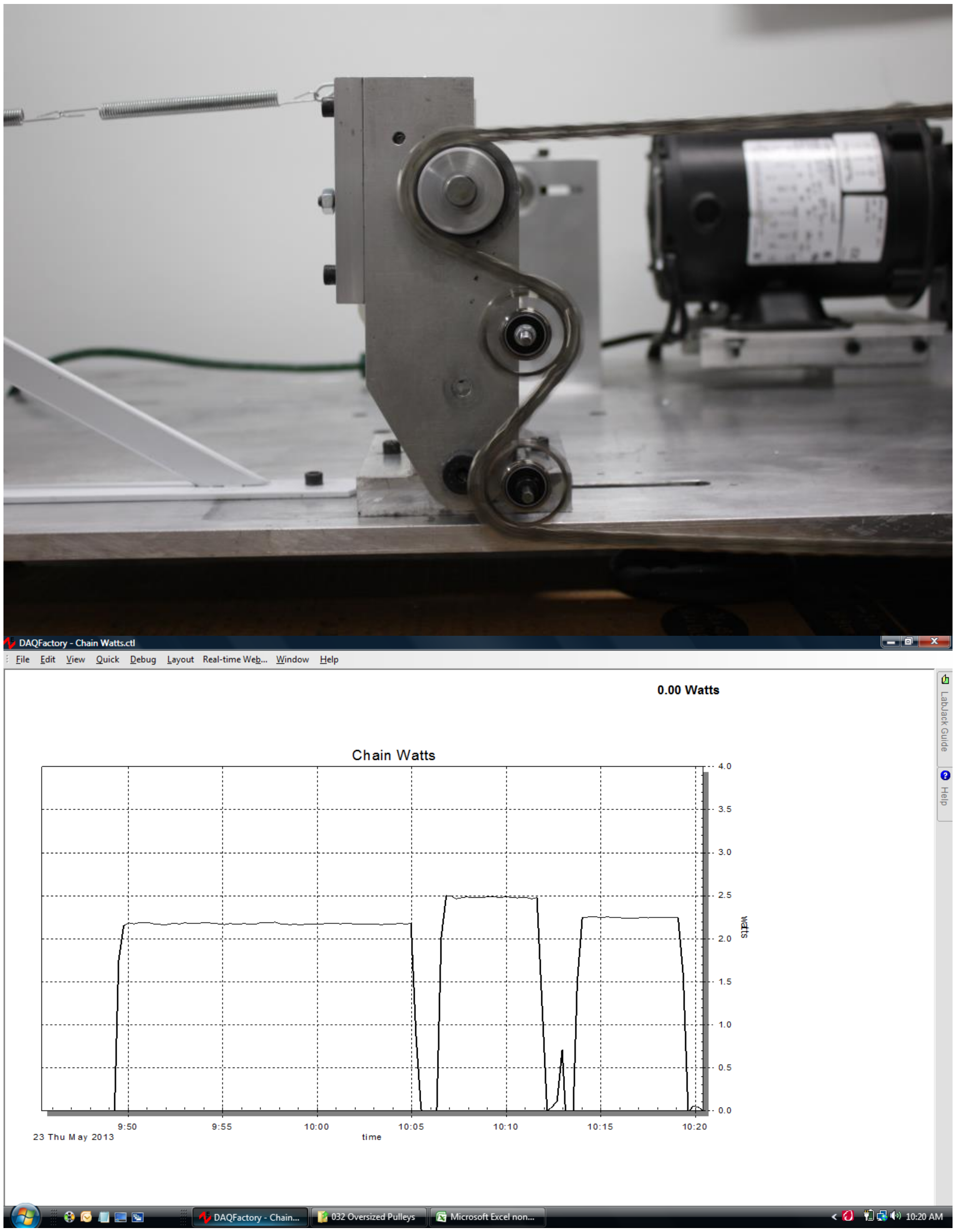
Dura Ace 13T-13T Combination.



RALTech 15T-15T Combination.

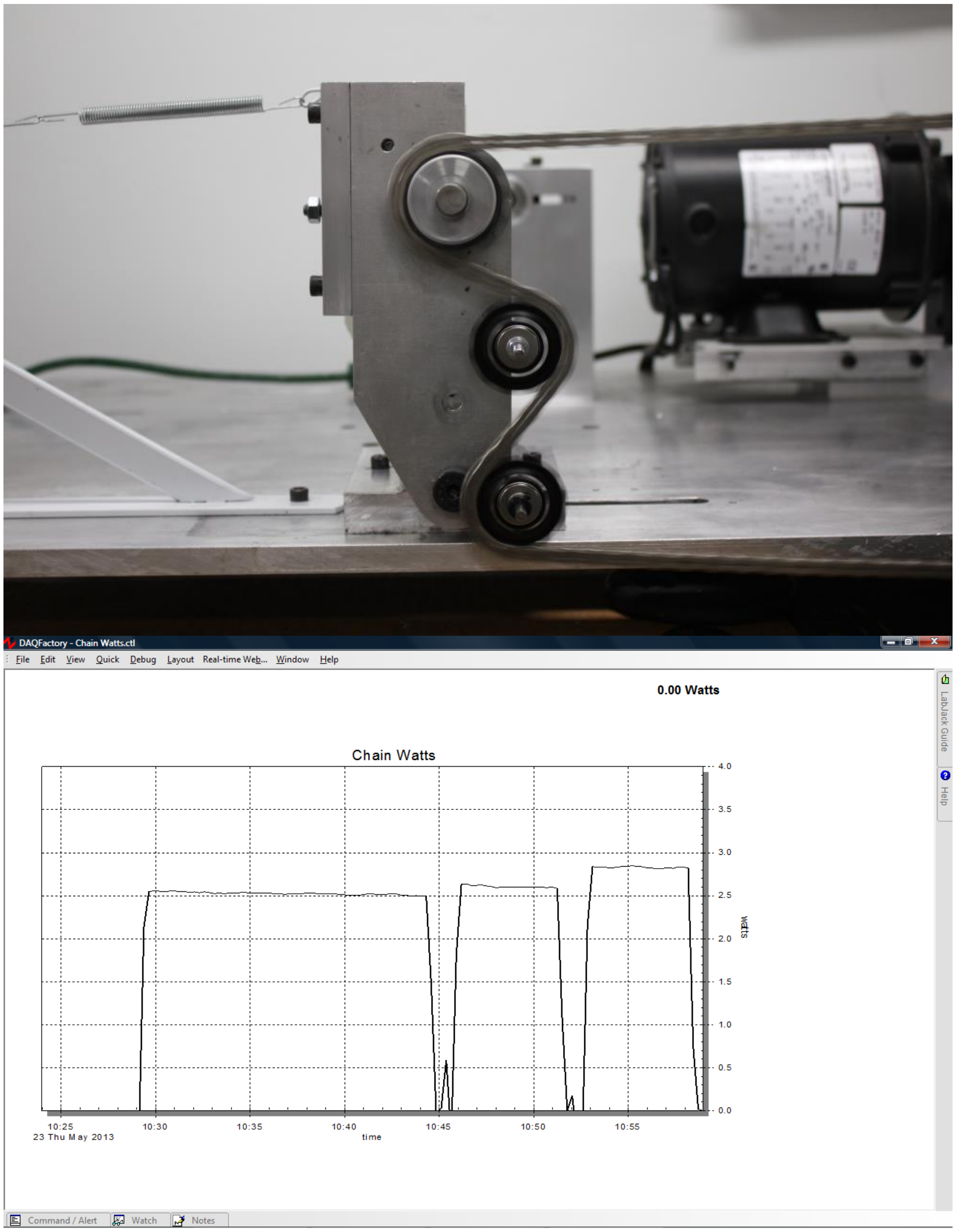


Berner 13T-15T Combination.

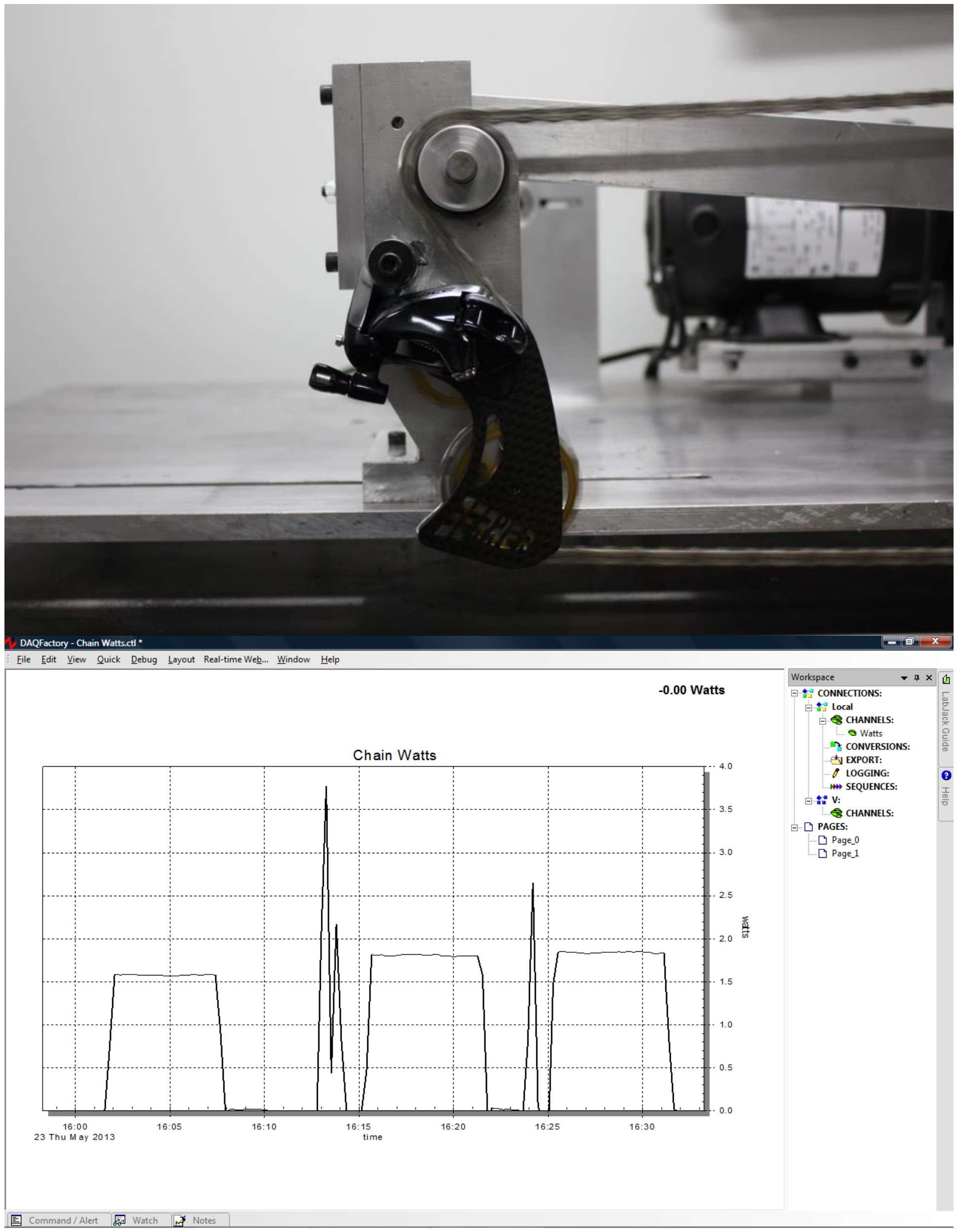


CeramicSpeed 11T-11T Combination.

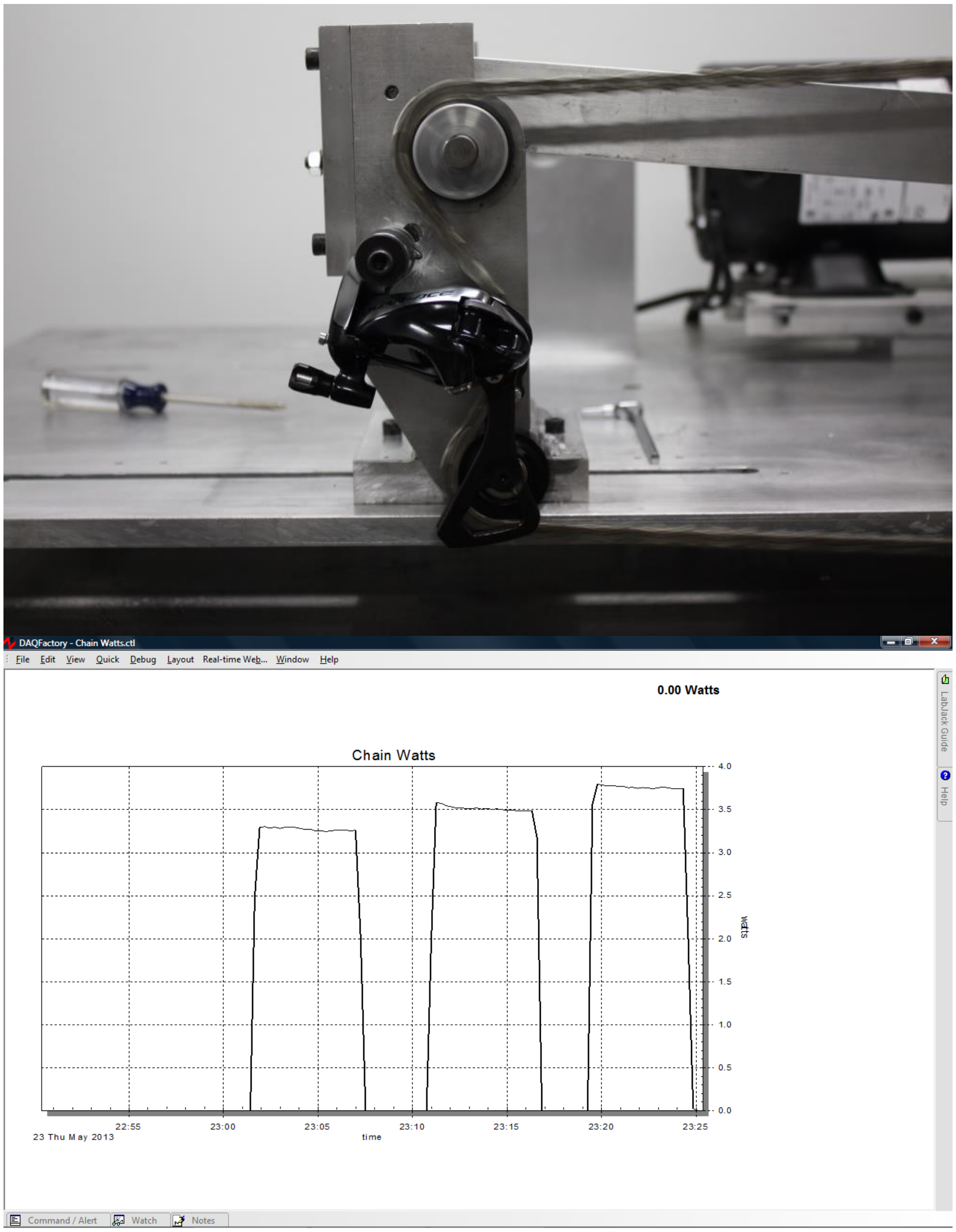
Note: the order of the second and third chains, the Shimano and SRAM, were inadvertantly switched for this combination. Does not affect the average.



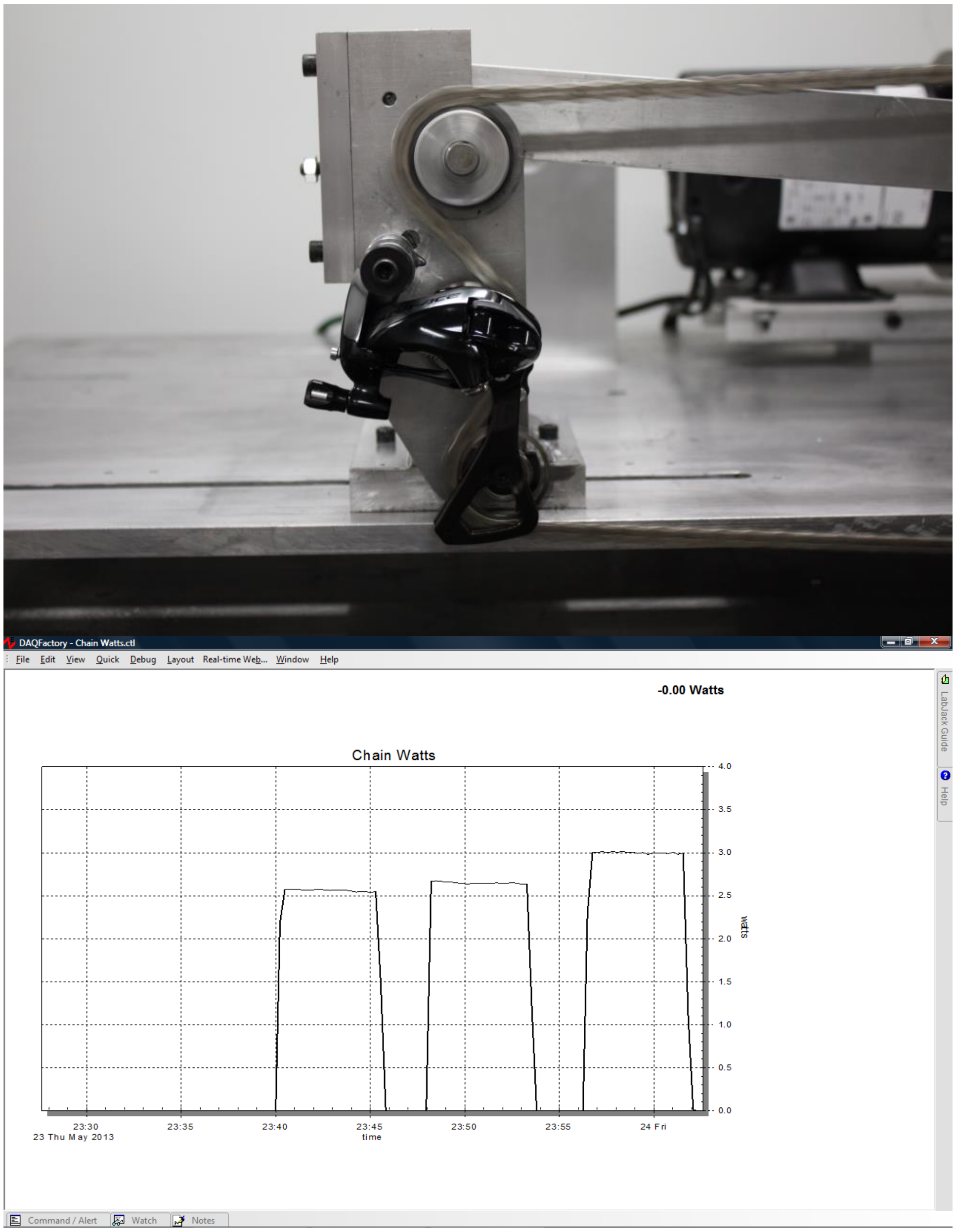
Dura Ace 11T-11T Combination.



Berner Cage, Berner 13T-15T Pulleys.



DA Cage, DA 11T-11T Pulleys.



DA Cage, CeramicSpeed 11T-11T Pulleys.