

CERAMICSPEED

FRIC**ION FACTS**

***Frictional Losses
of
Bearing Lubricants
&
Bearing Seals***

FULL REPORT

Note: *These tests involved the removal of the factory-installed bearing grease and replacement with aftermarket lubricants, and in some cases, removal of the factory bearing seals. These tests solely analyzed the effects of aftermarket lubricants on bearing efficiency, and **did not evaluate the effects these lubricants might have on bearing longevity.** Use of a lower viscosity or lighter lubricant in a bearing will most likely require more frequent re-lubrication to maintain proper life of the bearings.*

CONTENTS

OVERVIEW	8
<i>Lubricants Tested</i>	8
<i>Bearings Tested</i>	8
RESULTS- AVERAGE FRICTIONAL LOSSES	9
RESULTS- FRICTIONAL LOSSES BY LUBRICANT	10
<i>Specialty Grease Discussion</i>	11
EFFECTS OF FILL LEVEL ON LOSSES	12
EFFECTS OF SEALS ON LOSSES	13
<i>With Slip Oil</i>	14
<i>With Standard Grease</i>	16
RAW DATA / ALL DATA	18
DISCUSSION- BALL SIZE & BALL COUNT	19

LOSSES OF WHEEL BEARINGS- ESTIMATION 22
 Example calculation of BB + hub losses 22
FULL PROCEDURE 24
BOTTOM BRACKET EFFICIENCY TEST EQUIPMENT 25
LOADING CALCULATIONS 26

OVERVIEW

Seven lubricants of various viscosities and chemical make-up were tested on three different makes/models of BB30 bottom bracket cartridge bearings to measure frictional losses (friction).

The lubricants were selected to represent the categories of dry lubricant, low viscosity oil, medium viscosity oil, high viscosity oil, standard grease, and specialty grease. The sample lubricants were purchased by Friction Facts at retail outlets. Data presented is friction per pair (set) of bearings.



Lubricants Tested:

- | | |
|---|------------------------|
| 1. Powdered sub-micron Molybdenum Disulfide | (dry lubricant) |
| 2. Avid Slip R/C Bearing Racing Oil | (low viscosity oil) |
| 3. 3-in-1 Electric Motor Bearing Oil SAE 20 | (medium viscosity oil) |
| 4. Phil Wood Tenacious Oil | (high viscosity oil) |
| 5. Shimano Premium Grease | (standard grease) |
| 6. Finish Line Extreme Fluoro Grease | (specialty grease) |
| 7. Ceramic Speed TT Grease | (specialty grease) |

The three pairs of BB30 bearings used in this test are top-performing ceramic-hybrid bearings taken from the previously published Friction Facts Bottom Bracket Efficiency Test (2014). The sample bearings were purchased by Friction Facts at retail outlets.

Bearings Tested:

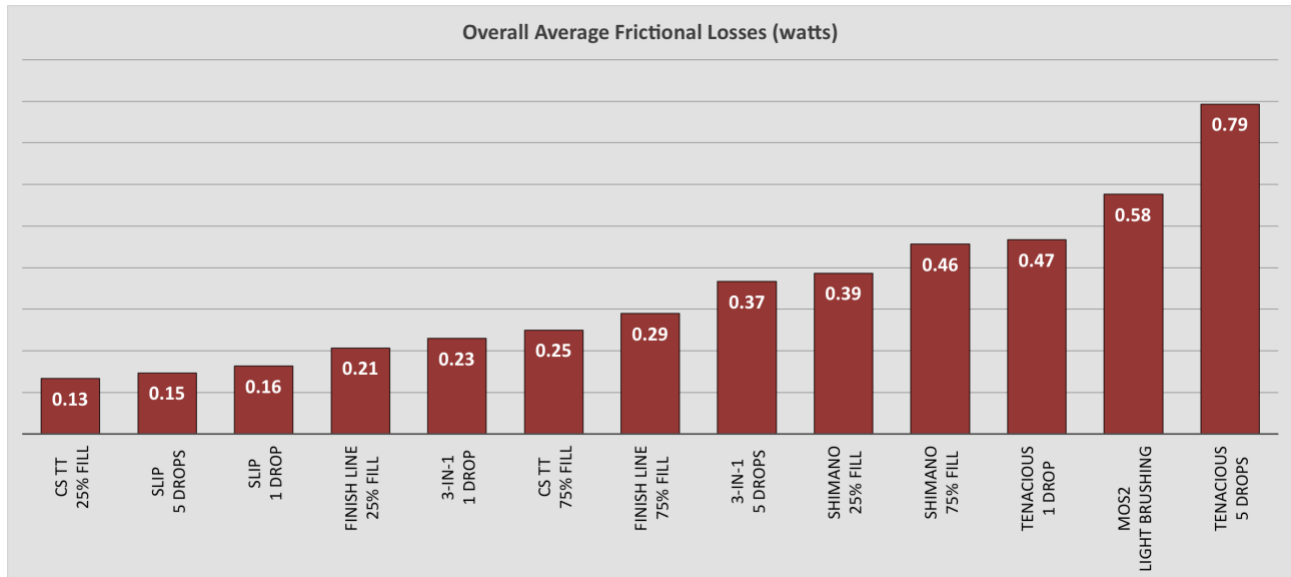
1. Enduro Zero BB30
2. Gold Race BB30
3. Ceramic Speed BB30 (non-coated version)

All seven lubricants were tested across the three pairs of bearings at two fill levels – low fill (25% for greases or 1 drop for oils) and high fill (75% or 5 drops). Note however that the dry lubricant was only tested at one fill level due to the nature of the substance. The dry lubricant was applied in a light dusting.

Two unique test combinations were added wherein the bearing seals were removed and the standard grease and the low viscosity oil were tested at high fill (75%) and low fill (1 drop) levels respectively. These test combinations were added to understand the effects of bearing seals on frictional losses with high and low viscosity lubricants.

A total of 45 individual tests were performed for this report.

RESULTS- OVERALL AVERAGE FRICTIONAL LOSSES

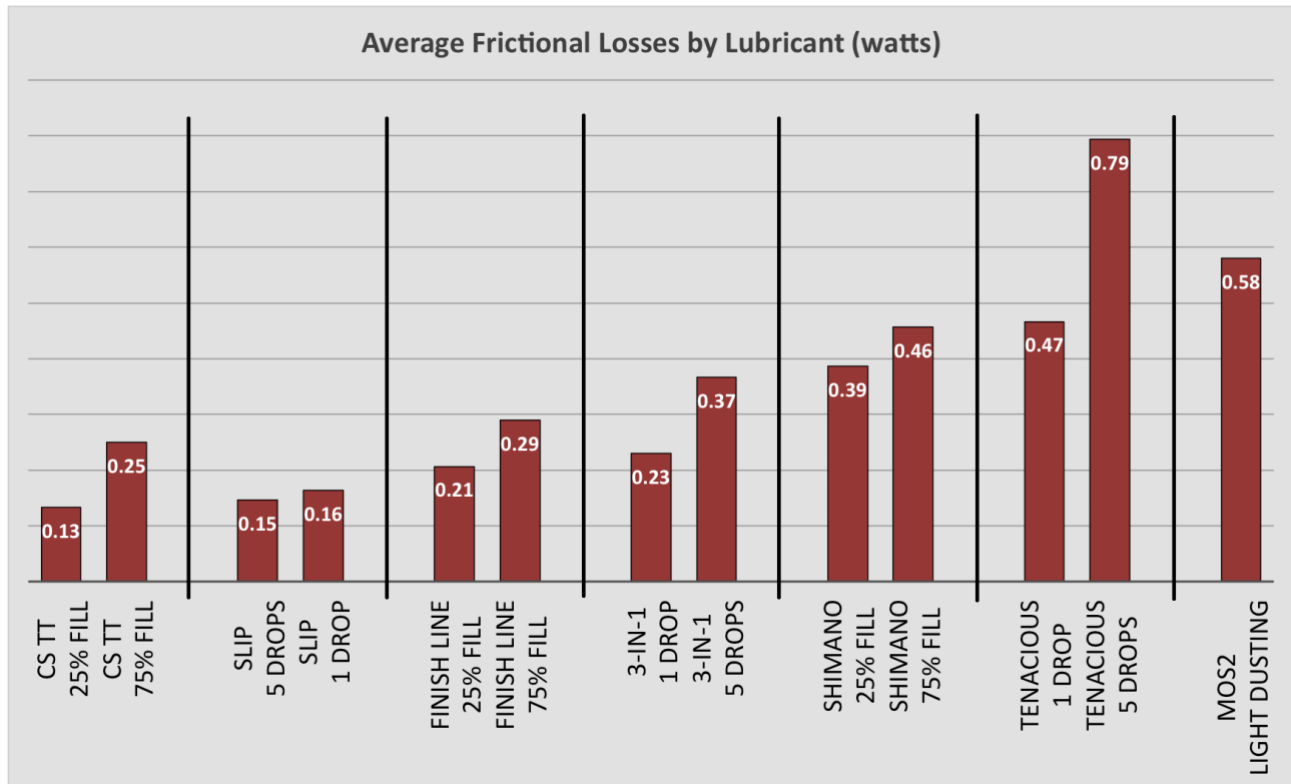


Graph 1: Average Frictional Losses (watts) of each lubricant at the given fill level per pair. Factory “stock” seals were in place on all bearings. The values in the graph are the **average** losses over the three sets of test bearings. Lower is better. Individual bearing results can be found below in the “RAW DATA” section.

- The **most efficient** lubricants, with the lowest **average** frictional losses are:
 1. **Ceramic Speed Time Trial Grease** **Fill Level – Low (25%)** **0.13 watts/pair**
 2. **Avid Slip R/C Bearing Racing Oil** **Fill Level – High (5 drops)** **0.15 watts/pair**
 3. **Avid Slip R/C Bearing Racing Oil** **Fill Level – Low (1 drops)** **0.16 watts/pair**
- The **least efficient** lubricants, with the highest **average** frictional losses are:
 1. **Phil Wood Tenacious Oil** **Fill Level – High (5 drops)** **0.79 watts/pair**
 2. **Powdered MoS2** **Fill Level – Light Dusting** **0.58 watts/pair**
 3. **Phil Wood Tenacious Oil** **Fill Level – Low (1 drop)** **0.47 watts/pair**
- The difference in frictional losses between the most efficient lubricant and least efficient lubricant is 0.66 watts/pair.

Up to 0.66 watts can be conserved with proper lubricant selection and fill level per set of bottom bracket bearings

RESULTS- AVERAGE FRICTIONAL LOSSES BY LUBRICANT



Graph 2: Average Frictional Losses grouped by lubricants. Values sorted by best performing (L: Best to R: Worst) within each lubricant group.

Prior to testing, it was hypothesized the dry lube (Powdered MoS₂) would exhibit the overall lowest friction, followed by oils with the next lowest friction (in order of viscosity from low to high), and finally the greases would exhibit relatively higher friction. Within the greases, the specialty greases would exhibit lower friction than standard grease. Yet, it was felt the friction of the specialty greases would still be higher than that of the highest viscosity oil. The experimental data proves otherwise.

Indeed, the oils did follow the hypothesis that higher viscosity leads to greater friction as the balls travel around the inner and outer races.

The low viscosity oil (Slip Oil) performed very well, as expected. However, the two specialty greases were relatively close to the Slip Oil, with the TT Grease actually exhibiting lower friction than the Slip Oil. The observed low friction of the specialty greases was not expected.

Standard grease outperformed high viscosity oil, which was also unexpected.

Why do specialty greases exhibit such low frictional losses?

Based on the manufacturers' descriptions, both the CeramicSpeed TT Grease and the Finish Line Extreme Flouro Grease use specific friction-reducing mechanisms not found in traditional greases, yet the two mechanisms vary greatly.

The Finish Line Extreme Flouro's friction reduction properties rely on chemistry. Per the Extreme Flouro web page, this grease uses 100% Dupont Perfluoropolyalkylether synthetic lubricant (PFPAE). Further research shows that PFPAE is a member of Dupont's "Krytox" family of 'super' lubricants, informally called "Liquid Teflon".

The CeramicSpeed TT Grease's friction reduction properties rely on dynamic physical properties, specifically, changes of state in viscosity. According to the TT Grease web page, while under load, the ball-race contact points experience significant decreases in grease viscosity, similar to what is seen in a light oil, thereby decreasing friction levels at the contact points.

The 'specialty' greases, while still labeled a 'grease', are very different in consistency than traditional grease. The specialty greases were noticeably less dense, more 'airy', and less sticky/tacky than traditional grease. Specifically, the Extreme Flouro Grease demonstrates a light 'whipped' food type of consistency.

Out of fairness, neither the Shimano Premium Grease nor the Phil Wood Tenacious Oil are marketed for superior friction reduction, as are the Slip Oil, the TT Grease, and the Extreme Flouro Grease. It is speculated that the Premium Grease and Tenacious Oil offer benefits of improved longevity at the cost of higher friction. Nonetheless, it was important to include high viscosity lubricants in the test matrix for comparative purposes.

Note: The 3-in-1 oil used in this test is 3-in-1 designed specifically for small motor bearings, not the more commonly found 'multi-purpose' 3-in-1 oil.

RESULTS - EFFECTS OF FILL LEVEL ON FRICTIONAL LOSSES

It was hypothesized that an increase in the lubrication fill level would increase viscous/fluid drag, and not necessarily increase the efficacy of the lubrication itself, therefore increasing the overall friction. This hypothesis was observed for all lubricants, with the exception of the Slip Oil. For the Slip Oil, the 5-drop friction was lower than the 1-drop friction. It is speculated that the Slip Oil is thin enough to the extent that 1 drop of the oil did not provide enough lubrication, and additional oil (total of 5 drops) increased lubrication efficacy. However, because of the low viscosity, the higher 5-drop fill level did not substantially increase the viscous drag. It is likely that the Slip Oil's extreme low viscosity requires that that more of it be used in order to maximize efficacy (5 drops is better than 1 drop). While not a significant difference in total friction was measured between the two different fill levels, long term durability may become a factor if not enough oil is used.

The opposite effect occurred in the case of the Phil Wood Tenacious Oil, 5 drops seemed to create an 'overfilled' condition. Oil was observed seeping out from the seals. The overfill caused the friction over the duration of the test to be rather unstable, randomly going up and down. It is speculated that overfilling the bearings with a higher-viscosity liquid lube created 'churning' in the bearing. According to the SKF Bearing website, regarding oil fill levels for bearings, "a further increase in oil quantity [above the proper oil level] increases frictional heat due to churning...". Churning can create a condition where the balls slide, rather than roll on the races. It is believed the 5-drop overfill with Tenacious Oil created this 'churning' effect, leading to the fluctuations seen in the friction measurements, and the relative high 5-drop friction.

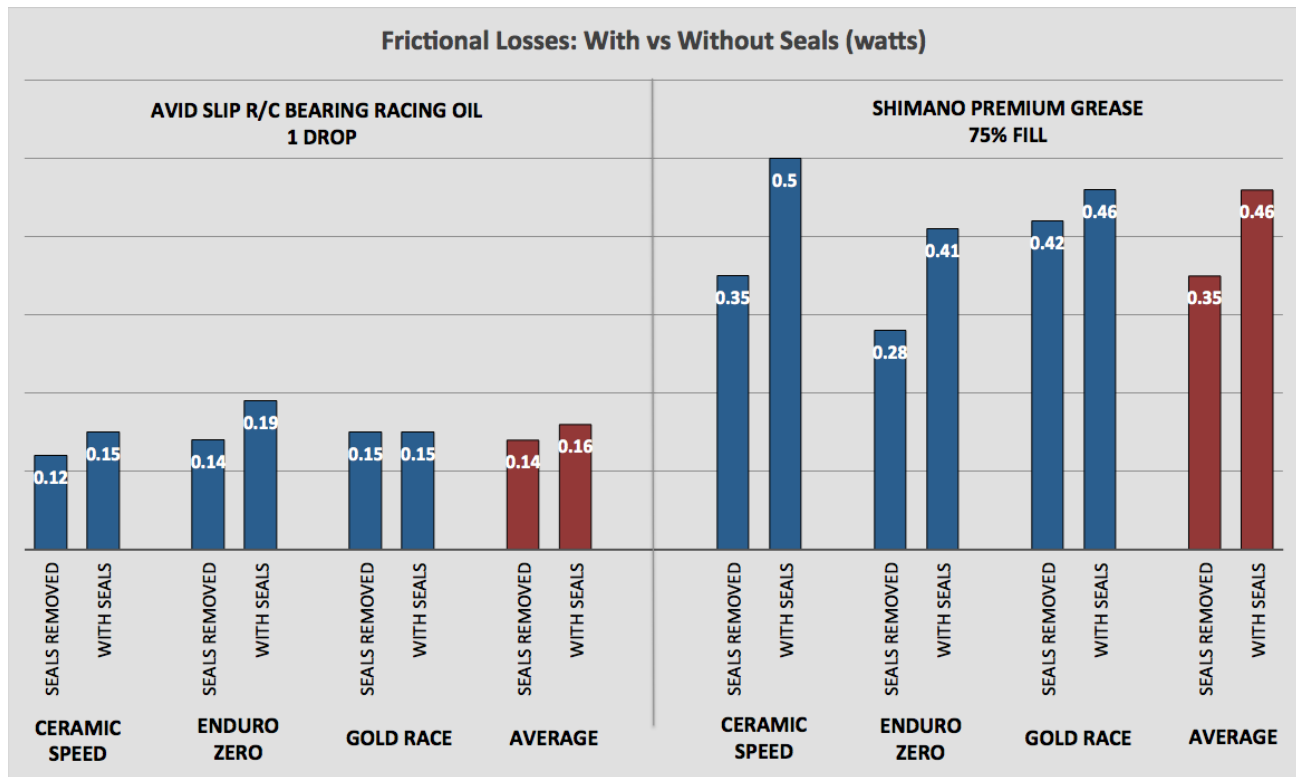
Churning was not seen in the 5-drop condition with either the Slip Oil or the 3-in-1 Oil. It was also not seen in the higher 75% grease fill level conditions.

While it was not directly tested in this experiment (5 drops was tested), it's possible that BB30 bearings can handle perhaps only 3-4 drops of high-viscosity oil before entering an 'overfilled' state. Yet with a low-viscosity oil, 3-4 drops might not be enough for longevity. A 'one-size fits all' approach to fill levels using oils should be avoided. Fill level should be based on the viscosity of the oil.

Note: For the three oils, the 'Fill Level' was determined by the number of drops; either 1 drop for the Low Fill condition, or 5 drops for the High Fill condition. While this method was simplistic and based on two defined drop quantities, it does not accurately reflect the volume of oil placed into each bearing, since one drop of Tenacious oil is larger in volume than a drop of 3-in-1 oil, which is in turn larger than Slip oil (higher viscosity oils create larger drops). A drop of each of the three oils weigh the following: Tenacious= 0.065g, 3-in-1= 0.043g, Slip= 0.040g. Assuming densities are similar between the three oils, the ratio of volume per drop of the three oils is related as follows:

Tenacious-100%, 3-in-1- 66%, Slip-62%. Therefore, by volume, 5 drops of Slip Oil has a similar volume to approximately 3.3 drops of Tenacious Oil. 5 drops of Tenacious Oil is similar to approximately 7.6 drops of Slip Oil. The differences in volumes per drop supports the need to tailor the number of drops used based on the viscosity of the specific oil.

RESULTS- EFFECTS OF SEALS ON FRICTIONAL LOSSES



Graph 3: Frictional Losses for each bearing, seals vs. no seals, of two lubricants.

Two lubricants were also tested with the bearing seals removed to determine the effects of friction on seal removal. Slip Oil at a 1 drop fill level and Shimano Grease at a 75% fill level were the two chosen lubricants to test the three sets bearings without seals. The two lubricants represent both ends of the viscosity spectrum - a smaller amount of a very thin lubricant, and a larger amount of a very viscous grease.

On average, the friction created by the seals alone was 0.02 watts/pair with the low viscosity oil, and 0.11 watts/pair with the standard grease.

Two factors can affect the friction created by bearing seals: firstly, the surface area and pressure level of the seals' lips which slide along the OD of the inner race (the bearing inner race, which is rotating, slides against the lip of the seal, which is stationary). Secondly, the lubricant which can create viscous drag against the inner flat surfaces of the seals (e.g., grease packed in the void between the stationary seal inner surface (face) and the rotating cage/balls).

Of the three bearing makes/models tested, two different (out of several current available designs) types/designs of seals were employed – a non-contact seal and a light contact seal. The Gold Race uses the former, while both Ceramic Speed and Enduro use what would be considered 'light contact'

seals. Both of these seal types are relatively low friction-producing seals, when compared to other types of seal designs such as double-lipped seals, which provide higher levels of contamination protection but also create higher friction.

SLIP OIL

When the bearings were tested with the low viscosity Slip Oil, the effects of the seal lip against the race (# 1 factor above) could be segregated from viscous drag effects (#2 factor above) and analyzed. Because of the very low viscosity of Slip Oil, the oil likely does not fill the void between the inner faces of the stationary seals and the rotating ball/cage assembly, thereby not creating viscous drag between these surfaces.

The Gold Race bearing non-contact seals do not actually touch the inner race (a gap exists between the seal and the race). Therefore, the lips of the seals do not create sliding friction, and, as expected, the removal of the seals did not decrease the friction in the Gold Race bearing.



Photo 1: The Gold Race Bearing with seals removed, showing the non-contact design, with no seal groove on the inner race



Photo 2: The Gold Race Bearing with front seal installed, showing the non-contact design, with the gap between the seal lip and inner race visible.

The Ceramic Speed and Enduro bearings use light-contact seals, wherein the lips of the seals lightly contact the inner race within a circumferential groove located around the outer diameter of the inner race. When tested with the low viscosity oil, removal of the seals decreased the friction of the Ceramic Speed and Enduro bearings by 0.03 watts/pair and 0.05 watts/pair respectively.



Photo 3: The Enduro Bearing with seals removed, showing the light-contact design, with the Inner Race Seal Groove visible.



Photo 4: The Enduro Bearing with seals installed, showing the light contact design, with the seal lip contacting the inner race.



Photo 5: The CeramicSpeed Bearing with seals removed, showing the light-contact design, with the Inner Race Seal Groove visible.



Photo 6: The CeramicSpeed Bearing with seals installed, showing the light contact design, with the seal lip contacting the inner race.

STANDARD GREASE

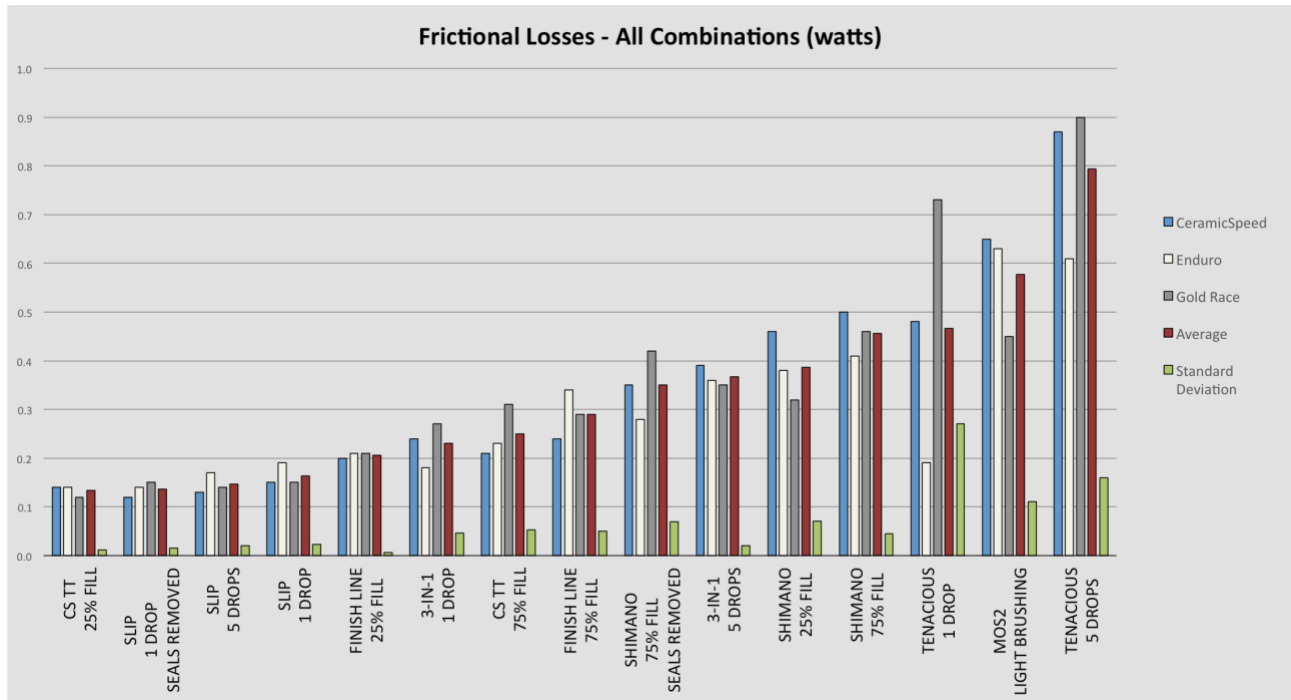
Seals have a greater effect on bearing friction when using standard high-viscosity grease than low-viscosity oil.

This was expected, and occurs (as mentioned above) because higher viscosity lubricants, especially traditional greases, fill the void between the inner face of the seals (which are stationary) and the ball/cage assembly (which is rotating). A volume of grease located between two rotating surfaces creates viscous drag, in addition to the friction created by the seal lip against the race. With standard grease, removal of the seals decreased friction by an average of 0.11 watts/pair.

It is important to note, while the decrease in friction by removing the seals was greater for the grease than the oil, this greater 'savings by removing the seals' observed with the grease does not offset the overall (absolute) lower friction seen with the faster lubricants. I.e., to create a fast bearing, start with a faster lubricant and keep the seals on, rather than using a traditional heavy grease and removing the seals.

Note: Seals are installed on bearings to *protect* the internals of the bearings from contaminants. Contaminants can create additional frictional losses, decrease longevity, and cause damage to a bearing. Selection of seal types should be based on the cycling application. The non-contact seals of the Gold Race bearing created the lowest friction of the two seal-types tested, yet by design they are gapped, which could potentially allow contaminants to enter the bearing, specifically when used outdoors in dusty, dirty, or wet conditions. The light contact seals of the CeramicSpeed and Enduro add a few hundredths of a watt of friction, yet the lip/groove designs do not have a gap, providing a higher level of protection from potential contaminants. Furthermore, neither of these two designs used in this test may be optimal for muddy-conditions riding such as mountain biking or cyclocross, where, for example, double-lipped seals provide an even higher level of protection, albeit at the cost of increased friction.

RAW DATA



Graph 4: Frictional Losses of each bearing, lubricant, seal, and fill combination. Standard deviation between bearings for each lubricant/fill combination was added (green bar).

Category	Lubricant Brand	Fill Level	Seals	Ceramic Speed	Enduro	Gold Race	Average	Std Dev
Specialty Grease	Ceramic Speed TT Grease	25%	Yes	0.14	0.14	0.12	0.13	0.012
Low Visc Oil	Avid Slip R/C Bearing Oil	1 drop	No	0.12	0.14	0.15	0.14	0.015
Low Visc Oil	Avid Slip R/C Bearing Oil	5 drops	Yes	0.13	0.17	0.14	0.15	0.021
Low Visc Oil	Avid Slip R/C Bearing Oil	1 drop	Yes	0.15	0.19	0.15	0.16	0.023
Specialty Grease	Finish Line Extreme Fluoro Grease	25%	Yes	0.20	0.21	0.21	0.21	0.006
Med Visc Oil	3-in-1 Electric Motor Bearing Oil	1 drop	Yes	0.24	0.18	0.27	0.23	0.046
Specialty Grease	Ceramic Speed TT Grease	75%	Yes	0.21	0.23	0.31	0.25	0.053
Specialty Grease	Finish Line Extreme Fluoro Grease	75%	Yes	0.24	0.34	0.29	0.29	0.050
Standard Grease	Shimano Premium Grease	75%	No	0.35	0.28	0.42	0.35	0.070
Med Visc Oil	3-in-1 Electric Motor Bearing Oil	5 drops	Yes	0.39	0.36	0.35	0.37	0.021
Standard Grease	Shimano Premium Grease	25%	Yes	0.46	0.38	0.32	0.39	0.070
Standard Grease	Shimano Premium Grease	75%	Yes	0.5	0.41	0.46	0.46	0.045
High Visc Oil	Phil Wood Tenacious Oil	1 drop	Yes	0.48	0.19	0.73	0.47	0.270
Dry Lubricant	Sub-Micron MoS2 Powder	dusting	Yes	0.65	0.63	0.45	0.58	0.110
High Visc Oil	Phil Wood Tenacious Oil	5 drops	Yes	0.87	0.61	0.90	0.79	0.159

Table 1: Raw Data (Frictional Losses in Watts per Bearing Pair)

DISCUSSION - BEARING BALL SIZE & BALL COUNT



Photo 7: Gold Race; 19 balls.



Photo 8: Ceramic Speed; 17 balls.



Photo 9: Enduro; 15 balls.

Each of the three bearings conform to BB30 dimensional standards, yet each bearing utilizes different ball diameters and ball count. Enduro uses the largest ball diameter of the three with a total of 15 balls. CeramicSpeed ball diameter falls between the other two bearings, and uses 17 balls. Gold Race use the smallest ball diameter and 19 balls. Typically, ball diameter is inversely proportional to ball count given the same ID and OD of a bearing.

The effects of the ball diameter/ball count did not seem to have an effect on performance when the bearings were tested with the lower friction-producing lubes (faster lubes).

However, it was noticed that a specific trend existed between the three bearings when tested with the higher friction-producing lube; the Phil Wood Tenacious oil. This lubricant is relatively tacky by design (and is perhaps the reason the name “Tenacious” is used). With the Tenacious Oil, the Enduro bearings exhibited the lowest friction, followed by the Ceramic Speed, and then by the Gold Race for both fill levels (Tenacious Oil at both 1 drop and 5 drops fill levels). Additionally, the standard deviation of friction between the three bearings was greatest with the Tenacious Oil vs the other lubricants. (see standard deviation values in green in Graph 4). The data show the friction by bearing for this higher viscosity lubricant is proportional to bearing ball count (and therefore inversely proportional to bearing ball diameter). It is speculated that, with a very high viscosity oil, and it seems only with a high viscosity oil, the ball diameter and ball count affects the friction. A greater number of smaller balls creates a faster ball spin rate, increasing the friction with a viscous oil. Larger diameter balls, on the other hand, with a slower spin rate, seem to create lower friction when used with a tacky thicker oil.

This trend, however, is not observed with 'faster' lubes – lighter weight oils and specialty greases. For the lubricants with the lowest friction-producing results (first five lubricants from the left of Graph 4), the Enduro bearings were not the most efficient of the three bearings for any of these five tests. Therefore, when using a lower-friction producing lubricant, ball diameter/ball count does not seem to have a predictable effect on friction.

FRictionAL LOSSES OF WHEEL BEARINGS - ESTIMATION

This report specifically tested frictional losses of BB30 bottom bracket bearings. Considering the addition of bearings found inside the wheel hubs, cyclists might well be interested in knowing the total potential frictional losses spread across both hub bearings and bottom bracket bearings, based on a given bearing lubricant.

Using the results for BB30 Cartridge bearings, the losses in a set of cartridge *wheel* bearings can be approximated. **The estimated total losses of a bottom bracket set in addition to the three sets of wheel bearings, i.e., the ‘watt-savings’ of the four pairs of bearings would be ~3.5 watts between top performing and lowest performing lubricants.**

While Friction Facts has not performed a full-scale comparison test of wheel/hub bearings, a limited number of frictional loss tests have been performed on hub bearings. Preliminary results indicate that a pair of load-supporting hub bearings produce roughly three times the friction of a pair of similarly-designed bottom bracket bearings- i.e., cartridge-style, radial groove, light contact seals. The term ‘load-supporting’ is used to differentiate the bearings supporting the rider load and the freehub bearings in the rear hub assembly.

When comparing BB30 bottom bracket bearings to load-supporting hub bearings, the radial force load on hub bearings is relatively similar to the radial force load on bottom brackets. Any potential variance is mainly due to differences in cadence, rider weight, and power output. Our tests assume a 250 watt rider output, 95RPM cadence, and 175lb rider weight plus bike & gear. We also assume a radial load of 114lbs for bottom brackets and 100lbs for hub bearings.

In terms of friction-creating mechanisms seen by the bearing, load-supporting hub bearings differ from bottom bracket bearings in the following ways : 1) The speed of hub bearings is about 4 times the RPM of bottom brackets, thereby increasing the friction level when compared to bottom brackets. 2) Hub bearings are typically smaller in overall diameter than BB30s, thereby decreasing the friction level. The overall net effect, as demonstrated by the data, is an approximate factor of three times greater friction created by a set of load-supporting hub bearings compared to bottom bracket bearings. (Granted, different types of hub bearings, such as cup and cones, or larger hub bearings in addition to other potential factors could very well change the multiplier. For the sake of this discussion, load-supporting hub bearing friction of three-times bottom bracket bearing friction is a fair estimation until further full-scale tests are completed.)

Freehub bearings, while not supporting rider load, are spinning and subjected to relatively light loads from the reactive force of the chain. Based on the testing of lightly loaded bearings, it is assumed the freehub bearings create a level of friction half that of the bottom bracket.

Example Calculation – Total Frictional losses of Wheels + Bottom Bracket:

For example, a rider is using a set of Enduro Zero BB30 bearings, and is also using Enduro cartridge wheel bearings with light contact seals and the same lubricant in both the bottom bracket and hub bearings. Assuming the friction in the *front* hub's set of load-supporting bearings is approximately three times that of the BB30 bearing friction, and assuming the friction in the *rear* hub, with two sets of bearings, one set for rider load, and one set for the freehub is approximately 3.5 times that of the BB30 bearing friction, the *total* friction of the BB30 set, plus the two sets of load-supporting hub bearings, plus the freehub bearings in the rear hub, is approximately 7.5 times the BB30 set *alone*. Translated into potential real-world frictional loss numbers, if a rider optimized their Enduro BB30 bearings with CS TT Grease at 25% fill, the friction level is 0.14 watts for the bottom bracket (see Table 1). If the rider also uses Enduro Zero hub bearings with the same CS TT Grease at 25% fill, the total losses for all three sets of bearings may be roughly approximated as:

$$0.14 \times 7.5 = 1.05 \text{ watts}$$

If the same bearing set up were filled with a standard grease, say Shimano Premium Grease at a 25% fill level, the resultant frictional losses would be:

$$0.46 \times 7.5 = 3.45 \text{ watts}$$

With Tenacious Oil, the losses would be:

$$0.79 \times 7.5 = 5.93 \text{ watts}$$

Therefore, in this example, the difference (watt savings) between using TT Grease and using Tenacious oil in the four sets of bearings is approximately 4.88 watts; quite significant.

Note:

This assumption is made based on a 250W rider output. The 7.5 times factor (for the total of both hubs and bottom bracket) should not change with higher rider output. Higher rider output increases load on the bottom bracket bearing, but not RPM (more torque equates to more reactive load on the bearing, cadence remains at 95RPM), and higher rider output increases RPMs of the hub bearings, but not load (load does not change, speed of bike increases, increases effective bearing RPM). Both of these factors (RPMs and Loading) affect bearing losses in a relatively similar linear manner. Freehub bearings experience higher RPMs and slightly higher loading with higher rider output. Yet the contribution of the slightly

higher loading to the overall drivetrain system friction is small enough that it will not be considered to change the 7.5 proportionality over a range of rider power output. Therefore, with a higher rider wattage output, the 7.5 times factor is still applicable. Granted, the absolute losses of the bearings would increase with higher rider output, yet a 7.5 times factor could still be used. For example, at 450W rider output, the same Enduro BB30 with TT Grease might produce 0.20 watts of frictional losses (at any rate, it will always be greater than 0.14W at 250W output). Therefore, the four sets of bearings combined might be $0.20 \times 7.5 = 1.5$ watts for a 450W rider.

Another Note:

This test used BB30 bearings. Based on the results of the previous Friction Facts Bottom Bracket testing, it was shown standard threaded standard and BB30 are very similar with regard to frictional losses. It is speculated similar trends would be seen with standard threaded bottom bracket bearings.

FULL PROCEDURE

The three sample bottom brackets used in this experiment were originally tested in the Friction Facts “Bottom Bracket Efficiency Test”. The three bottom brackets each received similar amounts of break-in time- multiple hours of run time from this original test, therefore no additional break-in was performed for this Bearing Lube Efficiency test.

Test Conditions:

1. A bottom bracket sample was installed in the BB30 Shell and placed in the equipment.
2. Shaft (axle) speed maintained at 95 RPM.
3. Each bottom bracket subjected to 114lb pure radial load.
4. Each test (45 total unique tests) consists of 10 minutes run time, or until the lubricant stabilized, and then a data point is recorded.
5. Lubricants were removed from the bearings by using an ultrasonic machine and 4 sequential solvent baths.
6. For fill levels, a “25% Fill Level” was created by filling the bearing with grease at a 90 degree sector. 75% of the bearing did not have grease.
7. A “75% Fill Level” was created by filling a 270 degree sector of the bearing with grease. 25% of the bearing did not have grease.

BB30 Bottom Brackets were used in this test, as opposed to hub bearings, simply due to the fact that Friction Facts had previously performed a Bottom Bracket test, and it was known which Bottom Brackets were top performing from this test. BB30 Standard was used, as opposed to another standard, due to ease of disassembly of the bearings to remove/replace the seals and clean/ fill with different lubricants.

BOTTOM BRACKET EFFICIENCY TEST EQUIPMENT

The equipment design comprises a set of ceramic fixture bearings, which support a shaft, which in turn support the bottom bracket installed in a frame shell with a hanging load applied to the shell via web straps. As the shaft turns, the shell, straps, and load remain stationary. Both the fixture bearings and the bottom bracket bearings are spinning. The total frictional losses of the system are measured, which includes the bottom bracket bearings and the fixture bearings. The fixture bearing losses (equipment losses) are removed from the measurement, resulting in a frictional loss value of the bottom bracket being tested.

The shell in which the bottom brackets were installed is an industry standard BB30 shell. The shell is the same bottom bracket shell used by frame manufacturers for frame construction, and was procured from frame component suppliers.

A load was applied to the shell through the use of wide nylon straps running across the top of the shell, to achieve an evenly distributed loading across the shell, as well as to provide equal loading on each of the right and left bearings. A shaft, acting as the crank spindle, with its outer diameter (OD) matching the bottom bracket inner diameter (ID) was inserted into the bottom bracket. The shaft, bottom brackets, and load straps are, in turn, supported by two ceramic fixture bearings. Clamps were utilized to fix the bottom bracket relative to the shaft and provide a light pre-load to the bottom bracket. Another set of clamps were utilized outside of the fixture bearings to laterally fix the shaft to the fixture bearings.

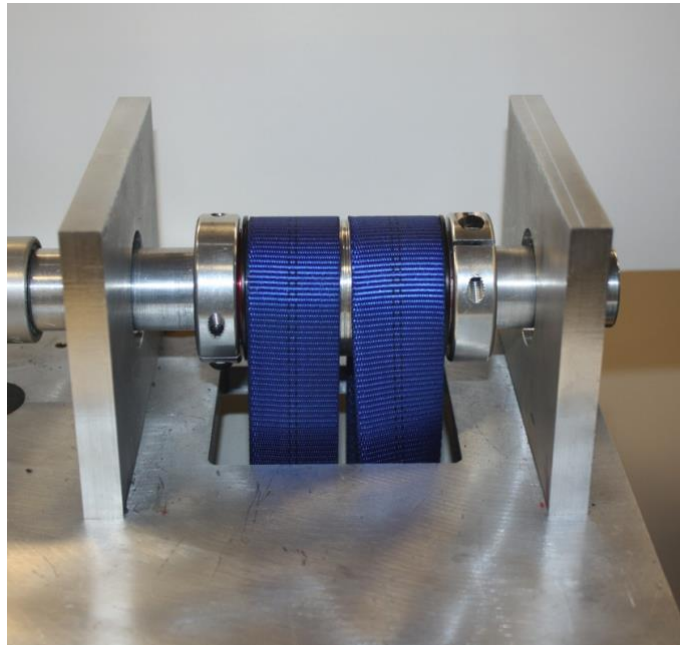


Photo 10: Side View showing support plates, fixture bearings, bottom bracket in shell, bottom bracket locating clamps, and loading straps. This picture shows a PF30 shell and the lips (black plastic) of the PF30 bottom bracket housing adjacent to the outer edges of the straps. (The fixture bearing locating clamps are not shown in this pic.)

The shell (with the bottom bracket installed internally), straps, and load remain stationary as the shaft rotates inside of the shell at 95 RPM. The rotational torque sensor, located in-line *between* the drive motor and shaft, measures the total friction (as torque) created by the two bearings in the bottom bracket, plus the two fixture bearings.

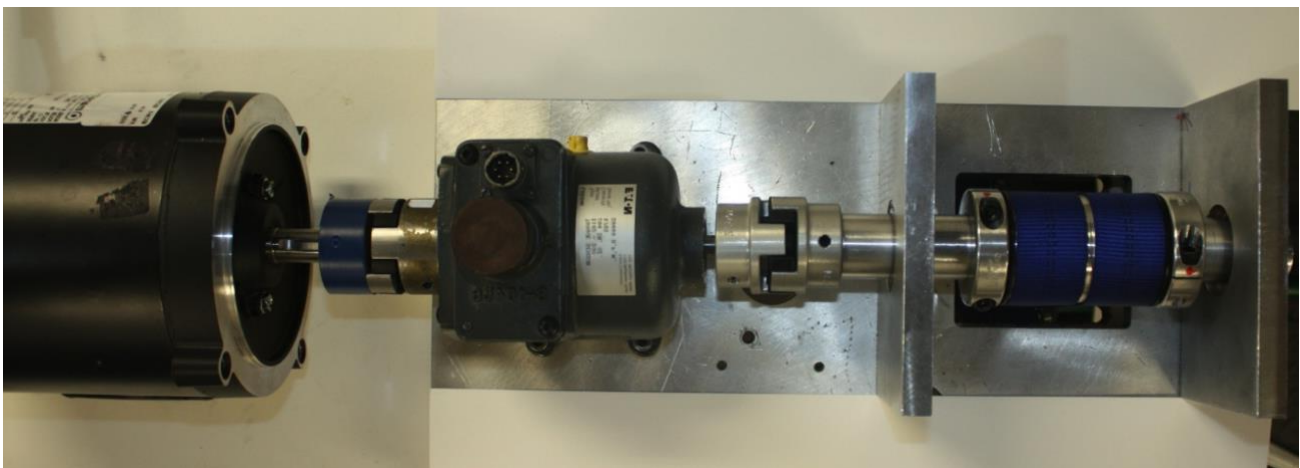


Photo 11: Top View of the test fixture showing (L to R) drive motor, rotary torque transducer, and bottom bracket in a shell with straps applied to the shell.

To maintain accuracy and consistency, the same calibrated fixture bearings were utilized throughout the entire test. The frictional losses of the fixture bearings are a known quantity from pre-test

calibration. The fixture bearing frictional losses are subtracted from the total measured frictional losses, resulting in the frictional losses of the bottom bracket under test.

The precision of the Bottom Bracket Efficiency Tester is +/- 0.01 watts.

LOADING CALCULATIONS

Bottom bracket bearings can be subjected to a wide range of loading conditions during typical riding. Bearing loads can be as little as a few pounds during easy pedaling, and rise to over 400 lbs during heavy acceleration, when full rider weight is applied at the pedal and the chain is in the small front ring. (Chain tension is greater when using the small ring due to a larger reactive force seen by the bottom bracket).

The load applied for this test (pure radial loading condition) was 114 lbs. This load is the approximate average load the bottom brackets would see during steady-state riding at 250 watts of rider output at 95 RPM.

Calculations are based on the following assumptions: 175mm crank length, chainring size of 53T (typical Large Ring for Standard Crankset), Pedaling speed of 95 RPM, and a steady state power output of 250W. The calculations also take into consideration the loading due to the rider pedal forces, the peak loading during the pedaling downstroke, the reactive force due to the tensioned chain, plus the cantilever effects (the point of load for the pedals and chain ring are outside of the respective centerlines of the bearings, creating a moment).

Drive-side and non-drive-side bearings are subjected to different loads at any given point of the pedal stroke, with the drive-side bearing experiencing higher average loads than the non-drive-side bearing due to the reactive force of the chain ring being on the drive side. The 114 lbs used in this test is the combined average of loads on both bearings equally.