Journal of Science & Cycling
Breakthroughs in Cycling & Triathlon Sciences

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Conference Abstract

A Test Design for Measuring Power Uptake of Bicycle Bottom Bracket Bearing Assemblies

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Received: 15 April 2024 **Accepted:** 19 April 2024 **Published:** 10 August 2024

Abstract: The scope of this study was to develop a test design to quantify the power uptake of bicycle bottom bracket bearings. For this, a caloric, contactless measurement laboratory design was set up with the potential extend to field application. The goal was to determine differences in resistance of 30 given bearing assemblies. The assemblies have been systematically modified in order to impact the power uptake during cycling relevant revolutions. Also 3 standard bearing assemblies have been tested for reference. In this test design, each sample was mounted into a vice, comprising a bottom bracket shell, a spindle, corresponding with the bearing dimension and two disks mounted on each side of the spindle's endings. For each run of the tests, the two discs and the spindle were set into rotation, exceeding 200 rpm and then let itself slowdown until a complete stop. During each of the runs, the angular velocity of the rotating disks was measured. The inertia of the rotating parts at a certain angular velocity represents the rotational energy in the system, hence its decrease over time the power uptake by the bearings. The tests revealed statistically significant differences in resistance amongst the 33 samples of up to 769%. A re-test was done in order to validate the designs reliability which revealed a high level of repeatability and reproducibility.

Keywords: Bicycle Bottom Bracket Bearing, Power Uptake, Rolling Resistance, Test Bench, Bearing Friction, Drivetrain Efficiency

1. Introduction

Efficiency in bicycle gear is subject to major efforts and interest in cycling industry [1] in general and in high performance cycling specifically. Aerodynamic drag, rolling resistance and energy dissipation in mechanic parts have been identified as main contributors to determine cycling gears efficiency already. Yet, the documents available barely present the methods being used in a reproducible way to match scientific or engineering quality standards. [2,3,4,5]

Amongst other parts, the Bottom Bracket (BB) assembly is in focus of industry to be constantly improved. While for consumers' longevity of BBs might be the most important feature, in professional cycling, a certain level of reliability given, the reduction of power uptake shifted into focus.

The design of commonly used ball bearings finds its roots in machine applications, where energy is usually vastly given such as in motorised vehicles, tooling machines or vessels. However, in cycling, an unnecessarily high energy dissipation (ED), caused by poor or poorly adjusted bearings, can make a difference for a rider, whether being victorious or not. Already a few Watts more or less dissipated in e.g. a BB may impact the result of races.

The energy dissipation of BBs depends on a number of factors: their design, lubrication, their proper installation, their maintenance and so on. The constraining factors are usually difficult to be kept constant in field applications and therefore a like for like comparison is challenging. In order to address this, a laboratory test jig was established, to reliably measure the energy dissipation / power uptake (PUT) of BBs in standardised conditions. After having been proven to be reliable, the design is supposed to be extended into a field application later on.

2. Materials and Methods

A selection of 33 different BBs was given to be discriminated by its PUT. All BBs were non threaded, press-in design BBs. The BBs differed in BB shell standard, axle diameter, bearing material and lubricant. In order to measure the PUT in a minimal invasive manner, a contactless test design was aimed to be set up. The test design therefore consisted of: two versions of BB shells; 1 x BBEVO386 and 1 x PressFit (Figure 1, #01), three different axle dummies; at ø30, ø29 and ø24 mm (Figure 1, #02), a laser sensor unit (LSU) (AWLG300m, Welotec GmbH, Laer, Germany) (Figure 1, #03), two disk shaped inertial masses (IM) of known weight (~4,3 kg), inertia (~0,017 kg m^{-2}) and dimensions (Figure 1, #04) and a mounting base (Figure 1, #05). One of the disks was featuring a polar drilling pattern of 24 equally distributed holes ($\partial a=15°$), facing the LSU as shown in Figure 1.

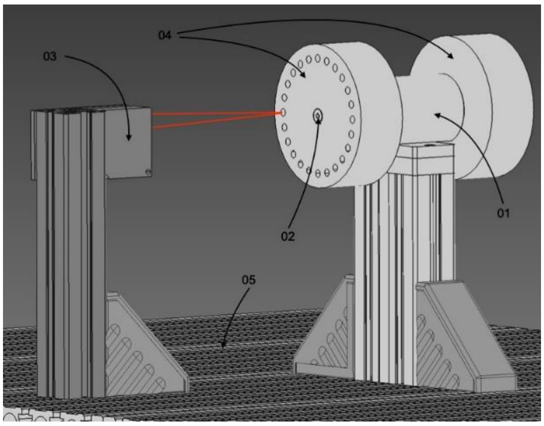

Figure 1. Test jig

A test of one BB included a set of consecutive ten trials. For each run of a test, the two inertial masses, mounted to the dummy axle were set into a rotation, using an external driver, disengaging after exceeding 200 rpm. Once spinning without any further external propulsion, the actual measurement process was started, with the laser beam engaging into the 24 drillings of the disk, facing the LSU (Figure 1). The altering signal in distance and time was measured and transformed into a digital signal, then providing true (hole engaged) and false (no hole engaged) information only (Figure 2).

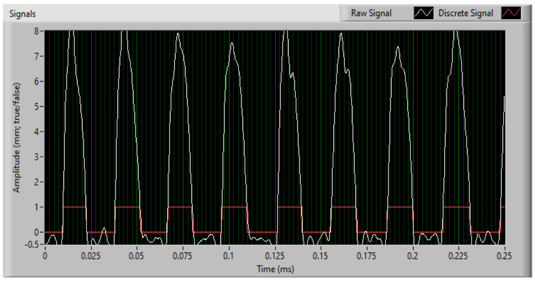

Figure 2. Signal conversion LSU

With 24 holes representing one revolution, increments of 15° could be discriminated, hence a rpm and a ∂rpm calculated. Knowing the mass and inertia of each; IM and axles, the rotational energy (Equation 1) of the assembly at a given rpm can be calculated.

$$E_{rot} = \frac{1}{2} I \omega^2$$

Equation 1

The friction / drag in the BBs is expected to cause the rpm to decrease over time and therefore the rotational energy. Eventually, the change of rotational energy over time was used to calculate (Equation 2) a resolving PUT of the BB.

$$P_{rot} = \frac{\partial \mathrm{E}_{rot}}{\partial \mathrm{t}}$$

Equation 2

During data processing, the signals within the range of 120 rpm to 50 rpm were used and a PUT at 90 rpm chosen to represent an application relevant rpm [5]. From each run, the PUT at 90 rpm was calculated and averaged over the 10 trials.

In order to justify the test designs reliability, a number of ten re-tests, with three randomly picked BBs (a, b, c) was carried out and examined for significant irregularities in context of assembling / installation. The re-test was performed by two different operators (1, 2), following the installation manual of the BBs manufacturer. The test included each of the BBs to be installed five times in a repeated, fix order (a1-b1-c1, a2-b2-c2). The data was used to calculate the variability caused by the operator (%AV^2) as well as the test setup (%EV^2) by applying the Average Range Method described in the Measurement System Analysis guidelines [7,8].

3. Results

The test design suggests to be sufficient to discriminate the used BBs from each other (Figure 3). PUT was detected between 0,13±0 W to 1,0±0,07 W, representing a range of 769%.

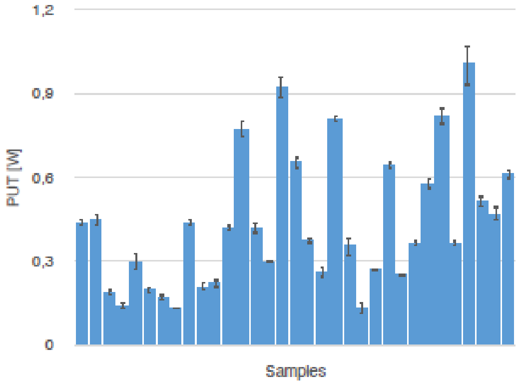

Figure 3. PUT of 33 samples tested.

The re-test did not indicate major intra-individual and inter-individual variability (Table 1). The variation due to the operator %EV^2 as low as 0,34% while the variation due to the test setup was 3,56%, resulting in an acceptable %GRR of 19,75%.

Table 1. Averages and ranges of five test repetitions from two operators and three BBs.

BB	Operator 1	Operator 2
	PUT Avg±SD [W]	
a	0,65±0,05	0,68±0,05
b	0,32±0,03	0,34±0,03
c	0,35±0,02	0,35±0,02
	PUT Range [W]	
a	0,12	0,14
b	0,06	0,06
c	0,06	0,04

The re-test did reveal a general drop in PUT after the first assembly (Figure 4). Each operator reported a decreasing friction in the press fit itself during each new installation of the same BB.

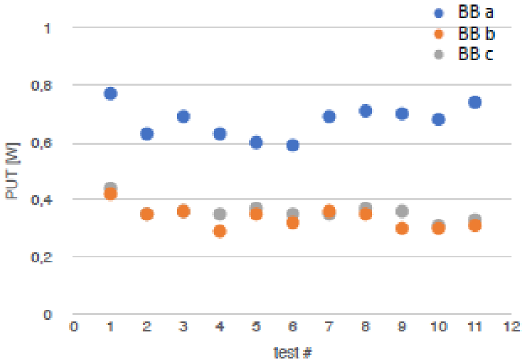

Figure 4. UT of three BBs in 11 test series, test #1 is the initial test, #2-11 the 10 repetitions of two operators.

4. Discussion

The data created with the method described, appears to be in correspondence with tests done before [1] and show similar PUTs in general. Though, when comparing with results from other tests, a slightly lower PUT can be identified for similar BBs. This can be explained the following ways:

- In the presented test design, the bearings run freely without any preload and without any additional support bearings (in contrast to previous test designs). Considering a linear dependency of drag force from normal force, measured values could be then extrapolated.
- The rpm of the previous test designs was 95 rpm rather than 90 rpm. Considering a linear dependency of rotational energy from angular velocity, the resistance can be expected to differ by the same ~5%.
- (applies specifically to the re-tested BBs) The BBs, used in this study are pressed in design assemblies and are supposed to be installed one single time only. The reason, given by the BBs manufacturer, for this is a considerably wear / deformation on the contact / mounting surfaces during removal and re- installation especially for the first and second installation. This usually goes along with a slightly less press fit, hence a lower bearing compression and is confirmed by the data of the re-tests that have been done.

The new test design provides a considerably low effort / investment method to reliably measure PUT in BBs. The absolute values for the PUT are considerably low, hence their differences. Though being statistically significant these differences may be not application relevant, which also finds confirmation with tests done before.

In context of before and thinking of measuring the PUT of an already in a frame / bicycle installed BB, this test design provides a whole new way of performance validation. The BB can now be already installed on a bike in order to objectively verify its PUT, bedding in effects and maybe even wear, by just replacing the crank set with the two IMs and the dummy axles. This specifically suggests for pressed in BBs. A suggested jig / design is shown in Figure 5.

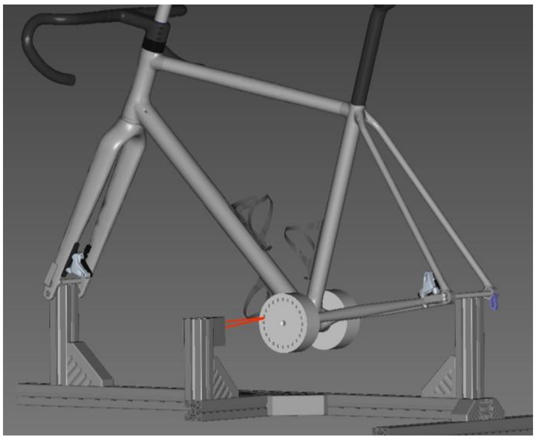

Figure 5. Suggested design for a test jig to measure PUT in bicycle assemblies

5. Practical Applications

The presented test design suggests being suitable for a variety of applications: (i) general benchmarking of BBs, (ii) an observation of wear induced performance changes over time in BBs, (iii) identifying the effectiveness of changes in design and engineering of BBs and frame moulds, (iv) identification of assembly flaws and (v) for setting bb shell diameters to performance supporting dimensions during production and / or assembly. A suggested application for v would be the assembly into an actual bicycle, fixed in a jig as shown in Figure 5. This way, the BB remains in the frame itself and will not be impacted by issues inherent in repeated assembles or biased by additional gear as mentioned in the discussion before.

6. Conclusions

The presented test design could be validated to be sufficient of measuring PUT of BBs. After all, the PUT measured is considerably small in amount, hence the differences amongst the BBs. Especially in high performance, professional cycling an application of the test design might be still useful. The general design is suggested to be transferred into a field application, with which BBs can be measured when installed in frames already as shown in Figure 5.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank Mr. Steffen Müller (TU Chemnitz) for his precious technical support in implementing the test rig. The authors would like to also thank Token Cycling Products for providing the samples tested.

Conflicts of Interest: The authors declare no conflict of interest.

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