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Conference Abstract

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The impact of drivetrain configuration on overall cycling efficiency: simulations, experiments and case studies from World Tour time trialing

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Keywords

drivetrain efficiency; metabolic efficiency; model-based optimization; experimental validation; time trialing

1 Introduction

Despite frequent displays of undisputed dominance in cycling's biggest road races, time trialing remains a test of precision, where victory is often determined by razor-thin margins. In all of the major time trials of the 2024 season, champions were separated from runners-up by time differences of less than 0.5% (or 9 seconds per 30 minutes). As a consequence, the pursuit of cycling efficiency has never been as relentless as today, with countless hours of wind tunnel testing being used to scrape off the last fraction of a watt from a cyclist's jersey. Besides aerodynamic efficiency, bicycle drive-train efficiency has received increased interest in recent years. On the verge of what could be a paradigm shift in bicycle drivetrain technology, the traditional front derailleur-based 2x systems are increasingly being challenged by "derailleur-killing" technologies such as 1x configurations and drivetrains equipped with hub gears. Whether or not said technology shift will actually happen, and if so in which of cycling's many disciplines, depends to a large extend on the proven efficiency of these new drivetrain concepts. In the current work, a comparative analysis of various drivetrain configurations is presented, based on a combined simulation-based and experimental approach, with case studies from World Tour time trialing in the 2024 and 2025 seasons.

2 Material and Methods

Cycling efficiency is affected by the selected drivetrain configuration through both metabolic and mechanical efficiency. The former refers to the dissipative conversion of metabolic energy into biomechanical power, which is impacted by cadence and hence by the gearing ratios offered by the bicycle drivetrain [1]. Mechanical efficiency, on the other hand, can be broken down into drivetrain efficiency (~frictional losses within the drivetrain components), aerodynamic efficiency (~drag losses due to drivetrain components exposed to an air stream) and gravitational efficiency (~surplus or deficit in weight compared to a reference drivetrain). In a well-maintained drivetrain, frictional losses account for approximately 4% of the total mechanical power (or 20 watts per 500 watts), with roughly two thirds arising from chain link interactions and the remainder coming from hub and bottom bracket losses. Since the optimal drivetrain configuration depends heavily on the targeted course, simulation is increasingly becoming part of any decision strategy, with experimental measurements serving primarily to validate the underlying models. In this work, a simulation-based drivetrain selection approach is presented based on physics-based modelling combined with experimental parameter identification and numerical optimization.

Drivetrain losses are modelled via the integration of three main power loss models:

1) a chain power loss model developed and experimentally validated by Spicer et al. [2], offering physics-based expressions for chain articulation loss, roller-tooth contact friction loss, and chainline offset loss;

2) a mechanical power loss model for geared and non-geared hubs developed in-house based on state-of-the-art gear and bearing power loss models [3]; and

3) SKF's friction loss model for deep-groove ball bearings [4]. The resulting drive-train power loss model is experimentally validated using two test rigs: a hub-level efficiency test rig (Figure 1), and a drivetrain-level efficiency test rig (Figure 2), that is also used to measure bottom bracket losses.

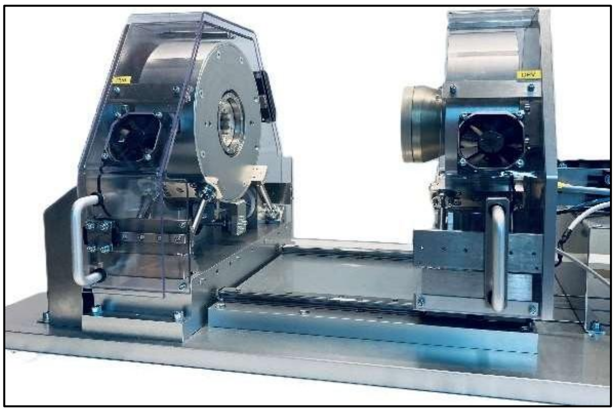

Figure 1. Hub-level efficiency testing

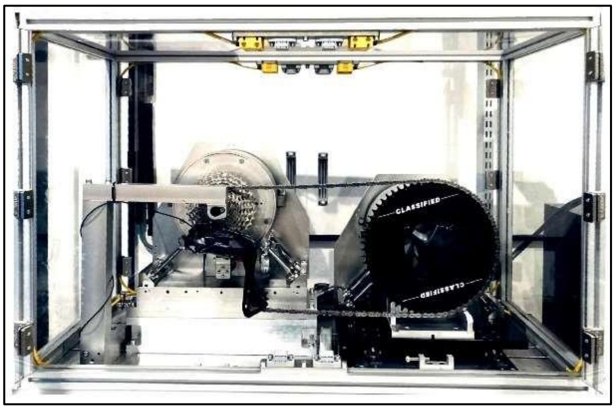

Figure 2. Drivetrain-level efficiency testing

Aerodynamic efficiency is accounted for using wind tunnel measurements, and differences in gravitational losses are included based on accurate weight measurements. Optionally, the impact of gear ratios on metabolic efficiency is taken into account based on efficiency-vs-cadence data found in scientific literature.

The experimentally validated drivetrain power loss model is integrated into an optimization algorithm that finds the optimal drivetrain configuration based on the selected course (divided into segments of constant elevation) and rider profile (power curve, weight, CdA value). For each segment of the course, the drivetrain power losses and resulting ground velocity are iteratively solved for, and the total elapsed time over all segments is minimized in function of drivetrain configuration.

3 Results

The above drivetrain optimization algorithm is used to assess the efficiency of several popular drivetrain configurations. Based on a number of key time trials in the 2024 and 2025 cycling season, the power losses of these drivetrains are compared (see Figure 3), providing actionable insights for those seeking to optimize drivetrain selection for specific race conditions.

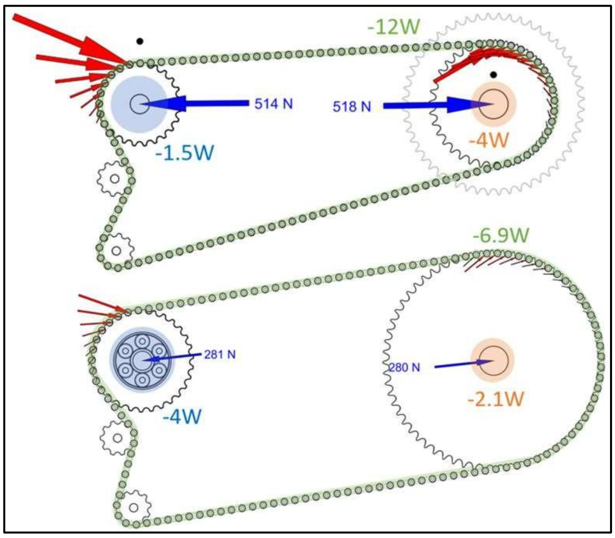

Figure 3. Comparison of power losses in a 2x configuration with conventional hub versus a 1x configuration with geared hub, @ 500 watts of input power. Green are chain losses, blue are hub losses, red are bottom bracket losses.

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

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