Measuring the Effect of Transmitted Road Vibration on Cycling Performance

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Introduction

Road racing bikes designed for specific functions Optimized for aerodynamics, stiffness, weight







Ride Quality = Vibration transmission

- Frame geometry
- Frame materials
- Viscoelastic frame inserts
- Components (wheels, tires, handlebars, etc.)

Literature Review

Davis & Hull (1981), Hull & Bolourchi (1987), Stone & Hull, (1995)
 ➢ Strength, stress and fatigue in road bicycle frame design
 DIN, JIS, ISO, and ASTM

Frame strength, fatigue, static stability, rigidity, and safety Thibault & Champoux (2000)

Modal characteristics of bicycles without a rider

Relation between components and vibration transmission Wojtowicki, Champoux & Thibault (2001)

- Front wheel bump impact test
 - Highest response ~50 Hz
- Testing on a floor with 1 m bump spacing
 - Inconclusive at distinguishing response between bicycles
- Recommended using a stationary road test simulator

No method/standard exists for quantifying ride quality

Study Objectives

Develop a system to characterize the effect of transmitted road vibration in road bikes

- Quantify vibration response
- Rider performance

Demonstrate the ability of the test method

Tested three different bicycle frames
Variables of interest

- Independent
 - Bicycle frame material
- Dependent
 - Vibration response of the frame
 - Cyclist performance



Treadmill w/ Bump

Extra-wide treadmill

- U Mass Amherst
- 5% grade
- Speed 19.3 km/h
- > 0.99 sec/rev
- Pedaling cadence of 77 rpm

Bump

- Created to induce wide spectrum vibration
- Cast using 75 Shore A polyurethane (poly 74/75)
 - Polytek, Easton, PA)



Bicycles

Supplier: Cervélo Cycles Inc. Toronto, Ontario **3 Frames tested** Steel (ST), aluminum, (AL) and carbon fiber (CF) All frames built in the same geometry Equipped with an identical set components Same wheel/tire set Tire pressure was set to 7.6 bar Identical riding position for all bikes Matched subject's own bike







Test Subject

Single subject used Eliminate bicycle size adjustment variables Mass and stiffness of rider the same for all trials **Professional cyclist** Kevin Monohan 2002, 2003 USPro Crit Champ Able to ride the treadmill Smooth pedal stroke \rightarrow Comfort and experience with V0₂ testing Height = 182.9 cm, Weight = 79.5 kg **Completed 3 treadmill habituation sessions** Total 1.75 hours



Instrumentation

Spriometry

- Rider energy expenditure, V02
- Measures inspired/expired gas
- Data complied every 30 s

SRM Powermeter Crankset

- Power, cadence, and heart rate
- Schoberer Rad Meßtechnik
 - Julich, Germany

Accelerometers

- Vibration response
- Mounted at seat post
 - Orthogonal with gravity
- CXL04LP3 3-axis, 100 Hz roll off
- Crossbow Technology, Inc.
 - San Jose, CA
- Data logging at 512 Hz







Test Protocol



Results

Vibration Data

Is the rider experiencing something different between the frames?

- Steel (ST), Aluminum (AL), Carbon Fiber (CF)
- Analyze accelerometer data
- **Rider Parameters**
 - If there is a difference, does it effect the rider?
 - Analyze rider power output, heart rate and energy cost (V0₂)

Results – Vibration

Accelerometer output for one treadmill revolution



Results – Vibration

30 Sequential Rear Wheel – Bump Impacts







- AL maximum values
- CF broad band around 60 Hz
- CF Damping in 30-35 Hz range

Results – Rider Parameters

Power, Heart Rate, Energy (VO₂) ➢ Data averaged over 200 s



Trend of stiffer bike requiring less effort
 Single subject design precludes generalization

of this result

Discussion

Vibration

- Magnitude of vibration transmission matches manufacturer's design intent
- PSD signatures of each bike frame may illustrate ride quality
- **Cyclist Performance**
 - No significant difference in rider performance results
 - Short-term test (5 minutes)
 - Longer test sessions needed
 - Hypothesize there is an energy cost of stiff bikes

Conclusion

Developed a system to characterize the effect of transmitted road vibration

- Bike response characteristics
- Rider performance

Demonstrated the ability of the test method

Distinguish between different bicycle frames
Future Work

- Understanding rider performance issues will require longer/more test sessions
- Test program easily extendable to bike components such as forks, wheels, tires, etc.

Instrumentation

SRM Powermeter Crankset

- Schoberer Rad Meßtechnik, Julich, Germany
- Rider power output, cadence, and heart rate, 0.5%
- Data logging via the Powermeter computer

Accelerometers

- mounted to the bicycle at the seat post using a specially fabricated clamping system
- Set to be orthogonal with gravity while on the treadmill
- Crossbow Technology, Inc., San Jose, CA
- CXL04LP3 3-axis accelerometer
 - High frequency roll-off of 100 Hz

Data logging 512 Hz

Valitech ReadyDAQ AD2000, Dayton, OH

Spirometry Equipment

Rubber mouthpiece

High velocity two-way non-rebreathing valve (dead space 95ml)

Hans-Rudolph, model 2700, Kansas City, MO

Inspired volume

Electronic pneumotacho-graph

Fitness Instrument Technologies, Quogue, NY

Expired gasses

- Directed into a 3.0 liter mixing chamber and
- Continuously sampled (250 Hz)
- Analyzed for oxygen and carbon dioxide concentration
- Ametek oxygen and carbon dioxide analyzers
 - AEI, Pittsburgh, PA

Test Protocol

Single Run

- Subject mounted bike, holding hand rail
- Subject fitted with spirometry equipment
- Treadmill slowly brought to target speed
- Subject releases handrail and begins riding
- Once settled in, data acquisition runs for 5 minutes

Transition

Wheels and instrumentation moved to next bike Test Matrix

Single run on each bike in one afternoon

• Test order: ST, AL, CF