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

- Strength, stress and fatigue in road bicycle frame design

DIN, JIS, IS0, 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
Methods

- Spirometry
- Power Output
- Bike Frame
- Test Subject
- Acceleration
- Treadmill w/ Bump
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 of 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
- Comfort and experience with V0₂ testing

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 ($V0_2$)
Results – Vibration

Accelerometer output for one treadmill revolution

- Treadmill Seam Impact
- Bump - Front Wheel Impact

Time, s

Acceleration, g
Results – Vibration

30 Sequential Rear Wheel – Bump Impacts

<table>
<thead>
<tr>
<th>Frame Type</th>
<th>Acceleration, g</th>
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<tbody>
<tr>
<td>AL-ST</td>
<td>5.85</td>
</tr>
<tr>
<td>AL-CF</td>
<td>5.47</td>
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<tr>
<td>ST-CF</td>
<td>1.06</td>
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<table>
<thead>
<tr>
<th>Frame Type</th>
<th>Range, g</th>
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<tbody>
<tr>
<td>AL-ST</td>
<td>4.62</td>
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<tr>
<td>AL-CF</td>
<td>4.93</td>
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<tr>
<td>ST-CF</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Z-Test

Maximum

Range

Frame Type
Results – Vibration

Power Spectral Density

- 16 - 2 sec time samples
  - Calculate 16 PSD’s, then average

AL Frame

CF Frame

ST Frame

- AL - maximum values
- CF - broad band around 60 Hz
- CF - Damping in 30-35 Hz range
Results – Rider Parameters

- Power, Heart Rate, Energy ($\text{VO}_2$)
  - 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