Performance Assessment from the Tire's Point of View

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Road Profile Users Group Conference
November 2, 2016

Road and Tire Shared Objectives

Both the road and tire industries share common goals for performance, but with different means and roles :

- Safety
  - Traction and braking
  - Handling
- Durability
  - Functional through expected lifetime (and beyond)
- Quiet
  - Environment
  - Vehicle passengers
- Comfort
  - Smooth ride
- Energy efficiency and environmental impact
  - Fuel economy
  - Green materials, manufacturing, and operations

Customers Requiring Tire Assessments

Tire performance assessment is required or requested by a number of different groups:

- Government agencies
  - Minimum performance requirements
  - Tire labeling
- OE Vehicle manufacturers
  - Tire performance specifications to meet vehicle requirements
- Consumer magazines and online websites
  - Published ratings and stories on performance
- Internal tire company sales and marketing departments
  - Desired performance for market positioning and sales
- Internal tire company QA department
  - Minimum performance requirements (greater than government requirements)

How Is Tire Performance Assessed?

The tire industry uses various means to assess the performance of their products

- Outdoor Testing
  - Single tire or on-vehicle
  - Specified special pavement surfaces and conditions
  - Dry, wet, snow, ice
- Indoor Testing
  - Single tire
  - Rotating drum or flat belt with specified surface
  - Dry, wet, snow, ice
- Simulations
  - Single tire or on-vehicle
  - Duplicate, as closely as possible, the corresponding outdoor or indoor test

How Is Tire Performance Assessed?

- Each tire performance area has different test methods, equipment, and test surfaces
  - Some require a single test procedure, while others can be assessed in multiply ways
- Test methods are created by
  - Government agencies to support their regulations (e.g., NHTSA)
  - Industry / government organizations (e.g., ASTM, SAE, ISO)
  - OE vehicle manufacturers
  - Tire companies

How Is Tire Performance Assessed?

- There are two main methods of assessment
  - Human senses (subjective)
    - Test performed on-vehicle by a trained driver/evaluator
    - Ratings and evaluation comments
    - Used primarily for noise, ride comfort, and handling
  - Instrumentation (objective)
    - Test performed on-vehicle or in the lab
    - Measurements made by equipment such as force cells, microphones, accelerometers, GPS units, etc.
- Future direction is for more objective measurements along with, or in place of, subjective assessments

Tire Performance Assessment

Descriptions will be given for each performance area

- Safety (traction and braking)
- Durability (tread wear)
- Quiet (noise and vibration)
- Comfort (ride comfort)
- Fuel Economy (rolling resistance)

Traction and Braking

- In the USA, Europe, and some other countries wet traction is part of the government-imposed tire labeling
  - Towed trailer testing on specified surface
  - Required value may be peak or slide friction, depending on the country
  - New USA tire labeling will keep wet traction, but may report peak friction instead of slide due to impact on ABS
- OE vehicle manufacturers specify tire traction and braking performance for their vehicle development programs
  - Dry, wet, snow, and ice surfaces at specified proving ground locations
  - Dry and wet testing on both asphalt and concrete surfaces, with both peak and slide reported
  - Towed trailer test and/or on-vehicle stopping distance test
  - Vehicle acceleration testing, especially on snow and ice

Tire Traction and Braking Testing

- Surface preparation is critical, and must follow procedures defined by government agency or OE vehicle manufacturer
- Goal is to have the “same” surface from test to test so that the tires’ performance can be assessed and compared
- Towed trailer test is basically the same for all required testing, based on ASTM F408, with differences being in test speed and loading conditions
  - Tests are performed at multiple speeds
  - Brake “chirps” to lock-up and hold for ~1.5 sec. to measure peak and slide

Tire Traction and Braking Testing

- On-vehicle braking test (dry, wet, snow, ice)
  - Specified initial speed and brake application
  - Measurement of deceleration vs. time and distance to stop
- On-vehicle traction / acceleration test (snow and ice)
  - Test tires at all vehicle positions or at a single position
  - Specified acceleration
  - Measure or rate slippage vs. speed

Snow traction test vehicle – single position test (Smithers)

Tire Changes to Improve Traction/Braking

- Tread compound
  - Lower hysteresis, higher grip, low temperature elasticity
- Tread pattern
  - Higher block stiffness, number of edges (slots and sipes)
- Tire construction
  - Belt layup, sidewall stiffness

- Trade-offs
  - Rolling resistance
  - Treadwear
  - Noise

Summer

All Season

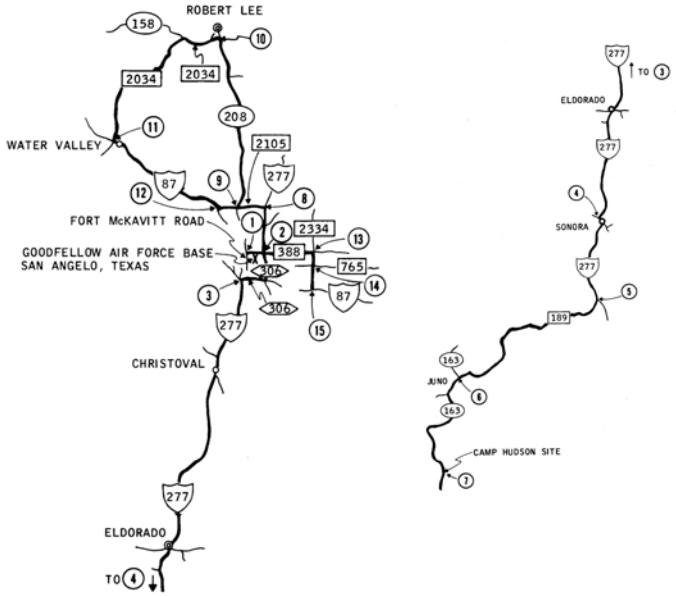
Winter

Tire Tread Wear

- Part of government-imposed tire labeling (e.g., USA UTQG and EU label)
  - On-vehicle wear measured on a specified course - typically public roads over a specified distance
- OE vehicle manufacturers also specify tread wear for tire development
  - On-vehicle wear measured on specified course over a specified distance
  - Course and test conditions are unique to each OEM
- Indoor drum tests are also performed
  - Simulate outdoor wear test loading
  - Some OE vehicle manufacturers accept indoor test results
- Tire manufacturers may also have their own internal tread wear test protocols (outdoor and indoor)

Tire Tread Wear Testing

- On-vehicle wear test routes are developed to represent aspects of real world driving conditions
  - Include city and highway portions – distance and type depends on the test protocol
  - Attention is paid to condition and maintenance of the road surfaces
- For example, UTQG tread wear is run on a 400 mile public road course near San Angelo, Texas for a total of 7200 miles
  - Vehicle set up and tire rotations are specified
  - Wear rating given relative to standard tire (SRTT) run on the same test fleet



Tire Tread Wear

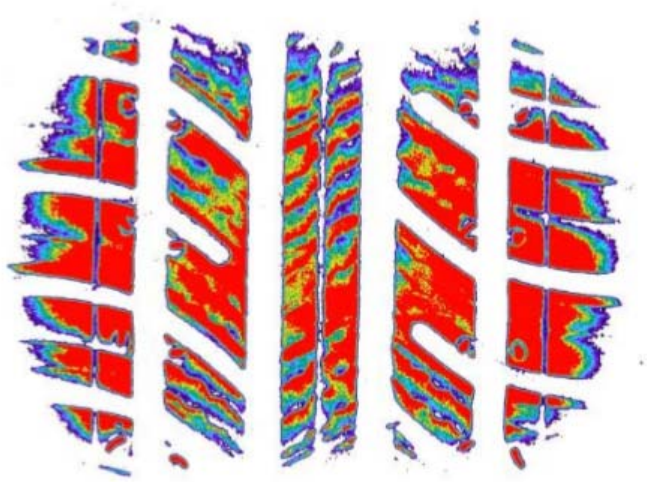
- Indoor drum tests are sometimes run
  - More efficient than outdoor tests
  - Large diameter drum (e.g., 10 foot)
  - Loads, slip angles, camber angles, speeds dynamically applied to simulate outdoor wear test
  - Medium grit surface on the drum, with powder (e.g., talc) applied to reduce rubber gumming on the drum surface
  - Wear is more aggressive than the on-vehicle test, so correlation needs to be made to outdoor test

Indoor tread wear test machine (MTS)

Tire Changes to Improve Tread Wear

- Tread compound
  - Higher abrasion resistance
  - Stiffer
- Tread pattern
  - Stiffer tread blocks
  - Slots, sipes, tie-bars
- Tire/road contact shape and pressure distribution
  - Tire geometry (e.g., tread cross-section radius)
  - Tire construction (e.g., belt layup)

- Trade-offs
  - Traction
  - Noise
  - Ride comfort



Noise and Vibration

- There are two main concerns for tire noise
  - Radiated to the environment (passby noise)
    - Concern of government regulators and people living alongside highways
  - Transmitted to the vehicle driver and passengers
    - Concern of OE vehicle manufacturers and people inside the vehicles
- In the USA, there are no government regulations for tire noise and vibration
- In Europe and some other countries, radiated noise (i.e., passby noise) is part of the tire labeling requirement
  - Tested on specified pavement surface at specified conditions
  - Measured by microphone at specified location

Noise and Vibration

- OE vehicle manufacturers specify noise and vibration requirements for tires developed for their vehicles
  - Noise and vibration experienced by vehicle driver and passengers, not environmental noise
  - Two transmission paths to vehicle interior
    - Structural – roughly under 400 Hz
    - Airborne – roughly above 400 Hz
  - Interior noise and vibration is strongly influenced by the vehicle (i.e., the transmission path)
- Tire manufacturers also perform tire noise and vibration measurements in the lab
  - On-drum noise
  - Static and on-drum modal vibration

Noise and Vibration Testing

- On-vehicle subjective noise and vibration ratings are made by trained evaluators
  - Special road surfaces at proving grounds, or selected public roads that contain the desired road surface features (asphalt, concrete, roughness)
  - Test surfaces and procedures are specified by the OEM
  - Ratings of various noise characteristics (sounds due to surface characteristics or occurring at selected frequency ranges):
    - Impact slap
    - Boom
    - Whine
    - Howl
    - Growl
    - Sha
    - Etc.

Noise and Vibration Testing

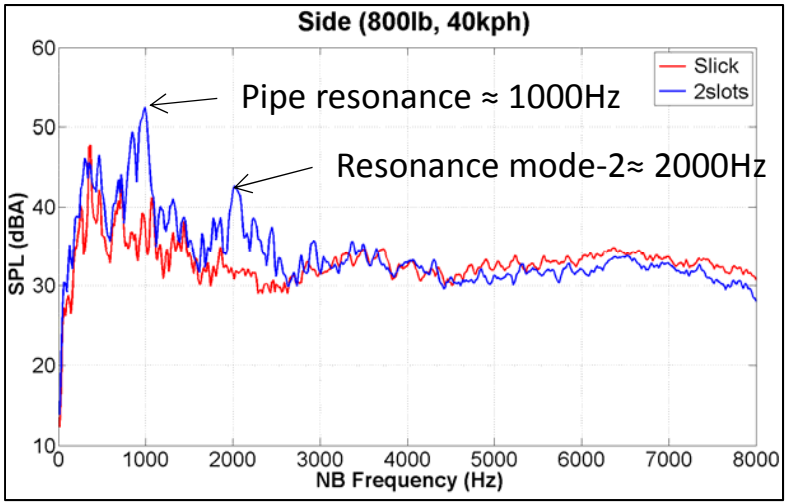
- On-vehicle objective noise and vibration measurements are increasingly being made using accelerometers and microphones inside the vehicle
  - Special road surfaces at proving grounds, or selected public roads that contain the desired road surface features (asphalt, concrete, roughness)
  - Test surfaces and procedures are specified by the OEM
  - Analysis methods of measured noise and vibration quantities are also specified by the OEM

Aachen head binaural noise measurement system (Head Acoustics)

Noise and Vibration Testing

- Tire noise and vibration transmission characteristics are measured by tire companies in their labs
  - Rotating drum with specified surfaces
    - Bare steel, medium grit, molded shell surface that duplicates a selected road surface
  - Microphones measure noise and force cells at the hub measure vibration force transmission

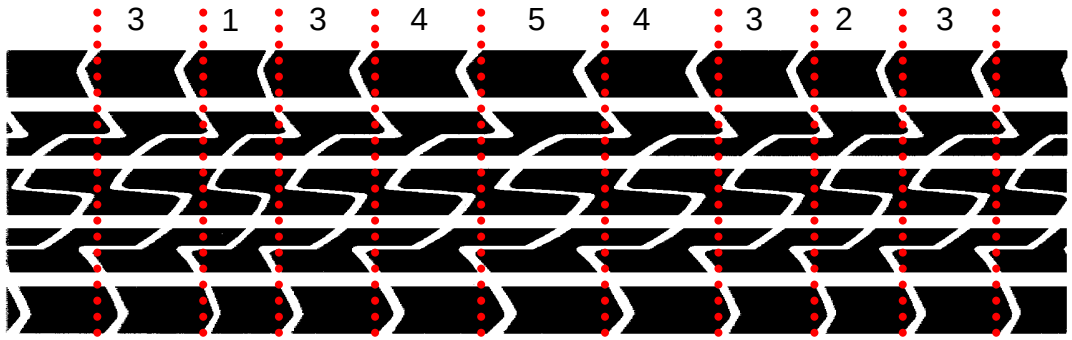
Experimental setup for noise measurement (Bridgestone Americas)

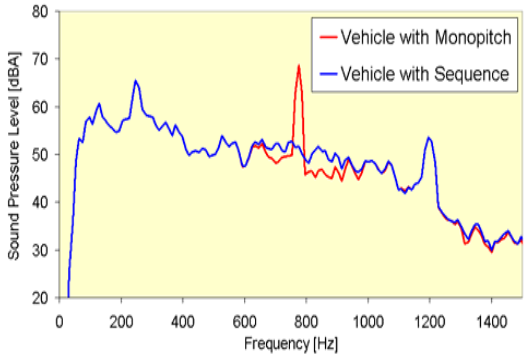


Tire Changes to Improve Noise & Vibration

- Tread pattern
  - Multiple block sizes and arrangement (pitch sequence)
  - Slot geometry
- Tire/road contact shape and pressure distribution
  - Tire geometry (e.g., tread cross-section radius)
  - Tire construction (e.g., belt layup)
- Sidewall stiffness and damping
  - Lower stiffness and higher damping

- Trade-offs
  - Traction and tread wear





Ride Comfort

- No government regulations for ride comfort
- OE vehicle manufacturers impose tire performance specifications to give desired ride feel for their vehicles
  - On-vehicle testing performed
  - Special road surfaces with desired features
  - Primarily assessed by subjective evaluations
- Tire manufacturers also perform lab tests to measure tire characteristics for impact
  - Drum test with a 10mmx10mm cleat on the surface
  - Measure forces transmitted to the hub
  - Evaluate amplitude, frequency content, and damping of the force signals

Ride Comfort Testing

- On-vehicle testing performed on special road surfaces with desired roughness or impact features
  - Expansion joints, small and large impacts, undulations, potholes, roughness levels
  - Specially constructed surfaces at proving grounds
  - Specially selected portions of public roads that contain the desired features
- Subjective ratings made by trained driver / evaluator for a number of characteristics
    - Plushness / rolling feel
    - Bounce and pitch
    - Large and small impact harshness and damping
    - Rough / coarse road isolation

Tire Changes to Improve Ride Comfort

- Tire/road contact shape and pressure distribution
  - Tire geometry (e.g., tread cross-section radius)
  - Tire construction (e.g., belt layup)
- Tread compound and pattern
  - Softer
  - Higher hystersis
- Tire stiffness and damping
  - Belt layup
  - Sidewall stiffness and hysteresis

- Trade-offs
  - Treadwear
  - Handling
  - Rolling resistance

Round leading edge better for ride comfort (*The Pneumatic Tire*, 2005)

Tire Rolling Resistance

- In Europe and some other countries, tire rolling resistance is already part of government-imposed tire labeling
- In the USA there are no direct government requirements (yet)
  - However, indirectly affected through OE vehicle manufacturers' CAFE requirements.
  - Getting tougher due to increasing NHTSA CAFE numbers and start of EPA greenhouse gas requirements
  - Tire rolling resistance will also be part of tire labeling once NHTSA releases their final-final rules
- Tire rolling resistance contributes about 4% - 7% to the car or light truck fuel consumption, depending on vehicle and driving condition (highway, city)
  - Although relatively small, OE vehicle manufacturers set tire rolling resistance specs and typically hold tire manufacturers to meeting them in order to meet CAFE

Tire Rolling Resistance Testing

- Tire rolling resistance is assessed through specified indoor test procedures
  - Tests performed on rotating drum or flat belt test machines
  - Follow standards (SAE J1269, SAE J2452, ISO 28580), but test conditions can differ by surface (bare steel or medium grit), load, pressure and speed conditions
  - Government tire labeling and OE manufacturers specify which test standard and conditions to be run
  - Equation available to convert values from drum to flat surface

Drum rolling resistance test machine (TMSI)

Tire Changes to Improve Rolling Resistance

- Rubber compounds used in the tire
  - Lower hysteretic tread, sidewall, other internal components
- Tire construction
  - Belt layup, sidewall stiffness
- Tread pattern
  - Higher block stiffness

- Trade-offs
  - Traction/braking (especially wet and snow)
  - Noise
  - Ride comfort

Summary

- Pavement and tire engineers share common goals to provide the desired performance to the public and to meet applicable government regulations
- There are many tire performance areas in which the tire/road surface interaction is very important
  - Tire companies are continuing research to better understand mechanisms and develop physical models and relations (e.g., friction equation that includes macro and micro pavement texture)
- Tire manufacturers expend considerable effort to develop, test, and produce products that meet their customer's needs and desires
  - Government agencies
  - OE vehicle manufacturers
  - Buying public