Friction Material Testing Overview

Jerry Curtis, Link Engineering Company, Inc.

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- Speed (rot): 368.1 rpm
- Speed (lin): 32.4 mph
- Pressure: 0.0 psi
- Force: 0.0 lb
- Torque: 0.0 lb*ft
- Decel: 0.0 fps/s
- Effct: 0.088
- Rotoc: 84 F
- Inotec Rad: 83 F
- Outect Rad: 82 F
- Drive On: Normal Cycle
- Brake On: Worn Out Cycle

Section 1.0 Performance Stop - Run #1
Perform 50 stops
From a speed of 45.7 mph to 0.0 mph
At 0.0 psi
When control temp is below 212°F
And cycle time exceeds 5.1 sec
Friction Material Testing Overview - Abstract

Data required for the accurate characterization of friction materials is acquired under controlled conditions in the laboratory and on the vehicle. In order to effectively interpret the acquired data, engineers must be familiar with both the procedures and equipment utilized. Many variables, such as timing, cost, sample availability, and data obtained from a particular test, are considered when selecting a testing methodology appropriate to the engineer’s scope of work. This presentation will educate the new brake engineer on the equipment and specifications available for the testing of friction material characteristics. Interpretation of the data and the correlation of laboratory and vehicle testing will be discussed. Topics covered will range from simple and inexpensive sample testing through complex full-scale friction material testing.

Inertia Dynamometer Overview

Vehicle brake simulations are conducted on an inertia dynamometer. To simulate the kinetic energy of the vehicle mass moving at speed, the dynamometer utilizes a mechanical mass fixed in increments to a rotating shaft. An electric motor is responsible for bringing the rotating mass up to a speed set point. Once the set point is reached, the motor releases control, and the braking system is responsible for bringing the rotating mass to a stop. The energy dissipated during the brake apply can be equated to the energy dissipated during a brake apply in a vehicle. To accommodate multiple vehicle platforms, dynamometers utilize a stepped shaft that accepts fixed increments of inertia.
Inertia Dynamometer

- Motor
- Inertia Cabinet
- Cooling Air Duct
- Tailstock and Brake Enclosure
- Base Plate
- Static Torque System

Dynamometer - Inertia Section

- Inertia Disks
- Inertia Shaft
- Inertia Cabinet
Machine Control – Test Procedure

- A review of the test procedure is necessary to determine if the test can be performed on the equipment available

- Some modifications to the procedure may be required

- Considerations include:
  - Maximum speed
  - Minimum and maximum inertia
  - Transducer full-scales
  - Clearance for mechanical fixturing
  - Special requirements such as capacitive probes, noise acquisition and raw data sample rates.
Machine Control – Apply System

- Pressure controlled deceleration applies
- Torque controlled deceleration applies
- Pressure controlled drag applies
- Torque controlled drag applies
- Pressure controlled brake profiling
- Torque controlled brake profiling
Data Acquisition

• Requirements may be specified in the test procedure
• When not specified in the procedure, default values may be used or the requestor can specify
• Considerations include:
  – Number of assigned and available channels
  – Data collection rate (frequency)
  – Summary data acquisition requirements (averages)
  – Raw data acquisition requirements (in-stop)

Data Acquisition – Summary Data

• Summary data is typically acquired for every stop in a dynamometer test
• Summary data may generally be considered as data that represents “averages”
• Examples of summary data:
  – Initial braking temperature
  – Final braking temperature
  – Average (by stop time or distance) torque, pressure, deceleration
  – Maximum stroke, force, torque, pressure, deceleration
  – Average coefficient of friction
Data Acquisition – Summary Data Example

Data Acquisition – Raw Data (in-stop)

- Raw data, or in-stop data, is the instantaneous data that is acquired during a brake apply.
- Raw data acquisition occurs at a sample rate (frequency) that is specified in the test procedure and set as a parameter in the dynamometer control program.
- Examples of raw data requirements:
  - ‘raw data, for this dynamometer procedure, will be acquired at a rate of 50 Hz for all channels unless otherwise specified’
  - ‘raw data will be acquired for each stop in the baseline, fade and recovery section at a frequency of 100 Hz’
Common Procedural Sections

Most inertia dynamometer based test procedures share common sections. While the specific parameters may change, common sections include:

- Instrument Check Stops
- Burnish
- Effectiveness
- Baseline, Fade, Recovery
- Durability / Capacity
- Wear
Instrument Check Stops

- Incorporated in most dynamometer procedures
- Typically 10 light duty applies performed from ambient temperature
- Used to validate machine set-up
- Helpful in identifying common start-up problems such as a reversed polarity thermocouple wire or an improperly bled brake apply
- Useful for verifying proper direction of rotation based on left or right hand orientation of the brake fixture.
Burnish

- Also referred to as bedding or run-in
- Commonly used in dynamometer and vehicle testing procedures to establish a uniform contact surface between the friction material and the rotor/drum
- Typically, 200-500 temperature controlled medium duty brake applies are used to burnish the material
- A friction stabilizing transfer layer is usually developed on the rotor/drum during the burnish
- Many dynamometer burnish procedures are derived from vehicle burnish procedures

Burnish

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Effectiveness

• Used to measure an output characteristic with regard to an input
  – Control pressure input and measure torque or calculate deceleration
  – Control torque or deceleration and measure pressure input
  – Control deceleration and measure torque or pressure

• Pressure controlled effectiveness
  – Linings with different friction levels will produce different torque levels
  – Linings with different friction levels will exhibit different rates of in-stop temperature rise
  – Dynamometer may reach torque cut-off setpoint before pressure setpoint is attained in an incrementally increasing pressure effectiveness

Effectiveness (cont.)

• Torque controlled effectiveness
  – Linings with different friction levels will do a comparable amount of work
  – Linings with different friction levels will exhibit comparable rates of in-stop temperature rise
  – Dynamometer may reach pressure limit setpoint before torque setpoint is attained in an incrementally increasing torque effectiveness

• Deceleration controlled effectiveness
  – Similar to torque controlled effectiveness
  – Same procedure can be used on multiple platforms without the need to re-program torque values appropriate for the vehicle platform
Effectiveness

Baseline, Fade & Recovery

The concept of a baseline/fade/recovery sequence is to measure the change in coefficient of friction as friction material is subjected to increasing temperatures.

- The baseline section may consist of 3 to 5 light duty brake applications made at a low temperature.
- In the fade section, a series of 10 to 20 heavier duty brake applications are made at a timed interval (30 - 60 seconds typical).
- During the recovery section, brake applications begin at a timed interval following the fade section. Apply levels for the recovery section are usually light duty as in the baseline.
- Typically, friction material will lose effectiveness as temperature increases. The recovery section is used to identify how quickly a material can "recover" to baseline characteristics.
## Baseline, Fade & Recovery

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## Baseline, Fade & Recovery

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Wear, Durability, Capacity

Wear
• Accelerated wear sequences may include drag or deceleration controlled brake applies
• Designed to quantify the wear characteristic of a brake component
• Apply levels can range from medium to heavy duty, and test durations can range from days to weeks
• Although the primary characteristic measured is wear, friction performance is often evaluated as temperature levels change throughout the test (temp-wear).

Durability / Capacity
• Durability testing is performed on friction material or hardware to exploit potential weaknesses exhibited under heavy duty or long duration applications
• A durability test may be conducted in an effort to crack a rotor or drum. Durability testing may also be used to wear friction material, detach noise insulators, or deflect components of the fixture.

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Dynamometer Test Procedures

There are many existing inertia dynamometer procedures available. Sources include:

- Industry standard procedures (SAE-J2430 B.E.E.P., JASO-406, FMVSS-121, etc.)
- Company specific procedures (Ford, GM, DaimlerChrysler, etc.)
- Custom or application specific procedures (created for a specific application or problem)
- In-house procedures (created by testing laboratories and derived from multiple sources)

Inertia Dynamometer Test Procedure Review

- Purpose of test
- Parts tested
- Overview of test procedure
- Controlling parameters
- Initial, intermediate and final inspections
- Data acquisition requirements
- Test duration –vs. – project timing
- Pass or fail criteria
- Reporting criteria
Machine Capabilities Review

- Dynamometer availability
- Test parts availability
- Speed, inertia and transducer full-scale requirements as specified in test procedure
- Mechanical fixturing availability and accommodations
- Dynamometer control program availability (lead time may be required for programming)
- Climate control requirements

Performing a Test

- Perform test
- Review resultant data (possibly before final report has been completed) and compare to test procedure requirements
- Review any documented deviations from procedure
- Review final report
- Determine if testing objectives have been met
- Provide feedback to reinforce or improve testing process
Vehicle Testing Overview

Testing of friction materials and braking components on the vehicle is another option available to Test Engineers and Project Managers. Applications suitable for vehicle testing include:

– Certification Testing (FMVSS-135)
– Product Benchmarking
– Product Development

Vehicle Instrumentation and Data Acquisition

To prepare a vehicle for testing, the following equipment is required:

• Transducers
  – Torque, pressure, temperature, speed, acceleration, noise, etc.

• Signal Conditioning
  – Equipment that scales and/or linearizes the output of the transducers (i.e. 0 to 3000 psi is scaled to a 0 to 10 volt signal for input into the data acquisition equipment)

• Data Acquisition
  – Software and hardware that “acquires” the data from the various transducers at a specified sample rate. The data acquisition software stores the data in a format that is convenient for data reduction
Vehicle Testing Procedures

Vehicle testing procedures vary as widely as dynamometer procedures. Examples of vehicle procedure test objectives include:

• Certification Testing
  – Used to certify a brake system for performance against a documented standard (FMVSS-135)
• Durability Testing
  – Performed on typical city or suburban traffic routes. Used primarily to simulate normal use of the braking system, but in an accelerated manner
• Product Development
  – Application specific tests are performed to determine potential weaknesses in the braking system

Vehicle Test Performance

Performing vehicle testing is more complicated and expensive than dynamometer testing. In order to prepare for a vehicle test, the following must be considered

• Timing
  – Vehicle testing typically takes longer than dynamometer testing (the dynamometer can be run unattended, the vehicle cannot)
• Staffing
  – Scheduling test drivers with appropriate skill levels in a manner that maximizes efficiency in vehicle run-time is difficult
• Facilities
  – Facilities for the installation of test hardware, installation of transducers, signal conditioning and data acquisition are extremely specialized and require the coordination of multiple disciplines
• Inspection
  – Inspections typically occur at mileage intervals and frequently must be performed outside of “normally” scheduled shifts to maximize vehicle run-time
Vehicle Data Interpretation and Reporting

Vehicle test data interpretation and reporting is conducted in the much the same manner as dynamometer data interpretation and reporting. To effectively interpret the data, the engineer must be familiar with:

- The test procedure performed
- The test set-up
- Requested or required deviations from procedure
- Pass or fail criteria specified in the test procedure
- Reporting requirements

Correlation Between Dyno and Vehicle Data

A direct correlation between dynamometer and vehicle test data is not something that just “occurs” without a considerable amount of planning. In most situations, successful vehicle testing is move to the laboratory to decrease cost and increase testing efficiency. To develop a dynamometer procedure that correlates with acquired vehicle data, the following must be considered:

- What exactly is being correlated (wear, noise, performance)
- Which brake applies or sequences from the vehicle test are candidates for inclusion in a dynamometer control program
- What is the acceptance criteria for correlation
Correlation (cont.)

- How will correlation be reported (correlation coefficient, Iso-Plot, etc.)
- Will each test on the dynamometer be compared to a baseline set of vehicle data, or will relative comparisons be made between the dynamometer data sets

Common properties successfully correlated between vehicle and dynamometer tests include:
  - Noise
  - Wear
  - Performance
  - DTV / Judder / Torque Variation

Improving Vehicle to Dyno Correlation

Improving correlation between vehicle testing and dynamometer testing is possible but requires much work. Steps needed are:

- Determine vehicle procedure to be correlated
- Scrutinize vehicle procedure and revise to account for “real world” actual practices
- Place an emphasis on developing a procedure that is repeatable and reproducible
- Perform study to determine correlation between vehicle tests executed using the same procedure (baseline correlation coefficient)
Improving Vehicle to Dyno Correlation (cont.)

• Determine what quantities can reasonably be correlated on the dynamometer with consideration for variables that are exclusive to vehicle or dynamometer testing
• Develop dynamometer procedure that attempts to correlate specific quantities from the vehicle test
• Conduct dynamometer testing, review data and modify control program until desirable correlation coefficient is achieved

While it is possible to improve correlation between data obtained on a test vehicle and data obtained on a dynamometer, it is extremely unlikely that dynamometer testing, or any other modeling or simulation testing, will ever fully replace vehicle testing.

Correlation Between Dynamometers

Dynamometer tests conducted on different manufacturer’s machines may usually be correlated directly assuming the following considerations:

• A documented quality system is in place that is appropriate to the scope of work being performed
• All machines utilized are properly calibrated
• Test procedures are identical and all machines are capable of performing the procedure without deviations (or with identical deviations)
Correlation Between Dynamometers (cont.)
• Even when the “required” inertia for the test is identical, careful attention must be paid to the “actual inertia” used
• Test reports are identical with respect to the quantities reported
• The main source of variation between tests run on different dynamometers can be caused by an inconsistent configuration of the data processing software, operator technique or interpretation of the procedure

Sample and Physical Properties Testing
• F.A.S.T.
• Chase
• Compressibility
• Swell & Growth
• Low Pressure Wear
• Thickness Variation
F.A.S.T.

- Friction Assessment Screening Test
- 90 minute test
- Constant torque / constant speed
- .5” x .5” x .125” sample size
- Reports coefficient of friction -vs- temperature
- Approximately $100.00 per test

Chase

- SAE-J661 and other custom procedures
- 2.5 hour test
- Performs cycles similar to dynamometer (baseline, fade, recovery, wear)
- 1” x 1” x .250” sample size
- Reports coefficient of friction -vs- temperature
- Approximately $150.00 per test
Compressibility / Swell and Growth

- SAE-J2468, SAE-J160 and other custom procedures
- Control parameters include test load, pre-load, ramp rate, temperature, number of cycles, cycle time
- Disc brake pads and various prepared samples
- Reports deflection -vs.- load
- Approximately $50.00 per test

Low Pressure Wear

- 5, 10 and 15 psi test runs (typical)
- 7 to 10 day test
- Used to determine “rotor kindness” of friction material samples
- Simulates brake off drag of friction material against rotor
- 1” x .5” sample size
- Approximately $1500.00 per test
Rotor Mapping

- DTV and TIR measurement using non-contact probes
- Applications include pre, during and post-test inspections and verifying induced thickness variation
- Report includes angle, Run-out and calculated thickness variation
- Approximately $50.00 per test