SAE International™

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2704

REAF. SEP2010

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Tire Normal Force/Deflection and Gross Footprint Dimension Test

1. Scope

This SAE Recommended Practice describes a test method for determining the vertical force and deflection properties of a non-rolling tire and the associated contact patch length and width. The method applies to any tire so long as the equipment is properly scaled to conduct the measurements for the intended test tire. The data are suitable for use in determining parameters for road load models and for comparative evaluations of the measured properties in research and development.

NOTE—Herein, road load models are models for predicting forces applied to the vehicle spindles during operation over irregular pavements. Within the context of this Recommended Practice, forces applied to the pavement are not considered.

1.1 Procedures

Two procedures are specified. The first procedure produces tire normal force/deflection data. The second procedure produces gross footprint, tire contact area, dimensions. Properly applied, the second procedure can simultaneously produce both normal force/deflection data and gross footprint dimensions.

1.2 Test Machines

This document is test machine neutral. It may be applied using any type of test machine capable of fulfilling the requirements stated in this document. The test machine must be capable of accommodating the tire sizes which are to be tested.

1.3 Rationale

J2704 has been reaffirmed to comply with the SAE 5-Year Review policy.

2. References

2.1 Applicable Publications

The following publications form part of the specification to the extent specified herein. Unless otherwise indicated the latest revisions of all publications shall apply.

2.1.1 SAE Publications

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J2047—Tire Performance Technology
SAE J2429—Free-Rolling Cornering Test for Truck and Bus Tires
SAE 770870—The Effect of Tire Break-in on Force and Moment Properties, K. D. Marshall, R. L. Phelps, M. G. Pottinger, and W. Pelz, 1977.
SAE 810066—The Effect of Aging on Force and Moment Properties of Radial Tires, M. G. Pottinger and K. D. Marshall

2.1.2 OSHA Publication

Available from the Rubber Manufacturers Association, 1400 K St., N.W., Washington, DC 20005.

OSHA Standard 1910.177—Servicing Multi-piece and Single Piece Rim Wheels—Available in wall chart form as #TTMP-7/95.

2.1.3 ISO Publication

Available from American National Standards Institute, Global Engineering Documents, 15 Inverness Way, East Englewood, CO 80112.

ISO Standard 17025—General requirements for the competence of testing and calibration laboratories

3. Definitions

The definitions that follow are of special meaning in this Recommended Practice and are either not contained in other Recommended Practices or are worded somewhat differently in this practice.

3.1 Contact Patch

This is the total area of the tire surface that touches the road surface. It is possible because of the large normal forces applied in the procedures specified in this Recommended Practice for the total area in contact to include parts of the tire surface that are normally considered to be parts of the sidewalls as well as portions of the tire surface normally considered to be part of the tread surface. Figure 1 is an example of an ink block contact area print.

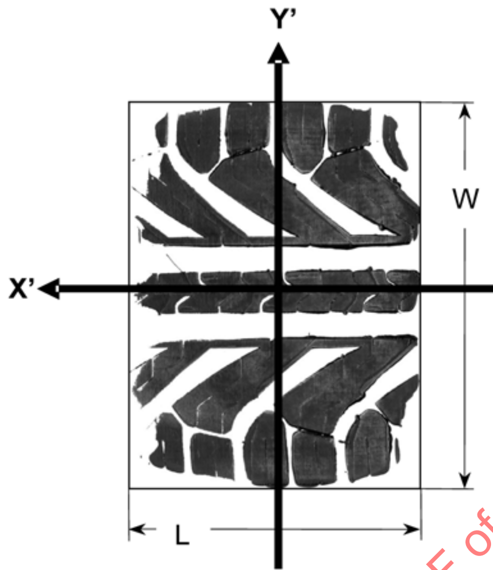

FIGURE 1—INK BLOCK CONTACT AREA PRINT

3.2 Contact Patch Dimensions

For purposes of this practice a rectangle is imposed about the contact patch as illustrated in Figure 1. The rectangle's sides touch the most forward, most rearward, leftmost and rightmost points composing the contact patch. The sides are parallel to the X' and Y' axes of the SAE Tire Axis System, which are shown in Figure 1.

3.2.1 CONTACT PATCH LENGTH, L

Contact Patch Length is the distance from the rearward edge of the imposed rectangle (the edge with the most algebraically negative X' coordinate) to its forward edge (the edge with the most algebraically positive X' coordinate).

3.2.2 CONTACT PATCH WIDTH, W

Contact Patch Width is the distance from the leftmost edge of the imposed rectangle (the edge with the most algebraically negative Y' coordinate) to its rightmost edge (the edge with the most algebraically positive Y' coordinate).

3.3 Test

A Test is execution of the procedure described in this Recommended Practice one time on one tire at a single set of test conditions.

3.4 Test Program

A Test Program is a designed experiment involving a set of the tests described in this practice.[1]

4. Nomenclature

Table 1 lists the symbols used in this document. For further information on items not in Section 4 of this practice please see SAE J2047.

TABLE 1—SYMBOLS DEFINED

Symbol	Defined Term
δ_Z	Vertical Deflection
F_Z	Normal Force
L	Contact Patch Length
p	Inflation Pressure
R_l	Loaded Radius
σ	Standard Deviation (Note Subscripts)
W	Contact Patch Width

5. Laboratory Quality System Requirement

The laboratory performing either of the procedures specified in this Recommended Practice shall have a quality system either conforming to ISO 17025 or which can be shown to be functionally equivalent to ISO 17025. The elements of such a system are assumed below and are not, therefore, specifically called out within this practice.

6. Apparatus

The required apparatus consists of a loading machine and test rims.

6.1 Loading Machine

The loading machine consists of a tire loading and positioning system, a measuring system, a flat surface simulated roadway, and the space housing the machine, which shall be maintained at 22 °C ± 2 °C.

6.1.1 Loading and Positioning System

The system shall maintain the tire with the tire/wheel plane within ±0.05° of perpendicular to the simulated roadway during all loading. Loading shall produce normal forces accurate to within ±1.0% of the test machine's full-scale normal force range. The machine's full-scale normal force range shall allow imposition of loads equivalent to at least 400% of the client specified 100% load. The hub may be either fixed or free to rotate about the spin axis.[2]

[1] There are many experimental possibilities: repeated tests of the same tire, tests of the same tire under multiple test conditions, tests of tires with different specifications (design details), application of this test as part of a series of different tests, etc.
[2] In a practical sense the hub of a properly aligned machine will not rotate during loading in this test so fixity is a moot point in this case.

6.1.2 MEASURING SYSTEM

Two coordinated measuring systems are required.

6.1.2.1 Load/Deflection Measuring System

This system shall measure normal force to within ±0.5% of the test machine's full-scale normal force range and loaded radius to within ±0.5 mm.[3] The system shall have a normal force range that allows measurement of forces equivalent to those existing at 400% of the client specified 100% load.

6.1.2.2 Contact Image Measuring System

The system shall give an image of the portion of the tire in contact with the simulated roadway at the target normal force imposed by the loading and positioning system. Examples of satisfactory imaging systems include ink block printing, frustrated total internal reflection photography or video imaging[4], matrix mat electronic pressure sensing system computer imaging, or such other systems as are capable of imaging the static tire/simulated roadway contact. The system shall allow determination of contact patch length and width within ±2.0 mm.

6.1.3 SIMULATED ROADWAY

The simulated roadway shall be a smooth flat surface free of loose materials and deposits. The material of which the roadway is made is unimportant so long as the roadway satisfies the following criteria.

6.1.3.1 The roadway shall be large enough to fully support the entire tire footprint.

6.1.3.2 The roadway and its supporting structure shall be sufficiently rigid so as to not change appreciably in either transverse or longitudinal orientation or in curvature under the machine's maximum applied normal force.

6.2 Test Rims

Test rims shall meet the dimensional tolerances of original equipment rims supplied on new vehicles and match the rim profile for the applicable tire as specified by the appropriate tire and rim standards association, for example, the Tire and Rim Association, Inc.

NOTE—Rim stiffness may have a discernable influence on the results. At this time, the presence of this effect has not been established. Further, there is not now a recognized way to appropriately characterize rim stiffness for use in this Recommended Practice. It is planned to address this question by research carried out prior to the five-year review of this practice.

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[3] Should the measuring system sense multiple forces and moments, the output shall be corrected for load cell interaction by a matrix method conceptually equivalent to that discussed in SAE J2429.

[4] This is a process in which the tire surface resting on a plastic membrane presses on a thick glass plate illuminated from the edges such that total internal reflectance occurs where there is no tire pressure (contact). Where pressure occurs, the total internal reflectance is modified proportionate to the applied pressure and a footprint image is produced.

7. Calibration[5]

Calibrate all measuring system components in accordance with the mandates of the written plan required by the laboratory quality system referenced in Section 5. Calibration must exercise all measuring system components over substantially their full range of application and must be performed not less than once each year. The reference standards and instruments used in measuring system calibration shall be traceable to the National Institute of Standards and Technology or the appropriate national standards organization with currently valid calibration certificates on file in the testing laboratory's files when the system's calibration is performed. Gains, offsets, and other pertinent performance measures and comments on system behavior during calibration shall be kept permanently on file within the testing laboratory's archives and be available to customers on request.

8. Preparation of Apparatus[6]

Preparation of the apparatus shall ensure that the test equipment meets its calibration at the outset of each test program and that the contact visualization system is functioning correctly. The precise process control method used to verify readiness of the apparatus is likely to be unique to an individual test site, but must be specified in writing within the quality system of the laboratory. The results of process control experiments shall be available to customers on request.

9. Selection and Preparation of Test Tires

9.1 Selecting the Tires for Good Comparability

The purpose of the test must be carefully borne in mind when selecting test tires since tire properties depend on numerous factors besides the tire design and materials. It is especially important to properly account for storage history (SAE 810066) and previous work history (SAE 770870). Due to the many complex questions that the test defined in this document may be used to address, specific tire selection recommendations can only be made for the case in which different tires are to be compared for pure design or materials effects. In that case, all test tires should be of approximately the same age, have been stored under essentially identical conditions, have experienced approximately the same exercise history, and have been sampled from production lots with similar statistical characteristics.

9.2 Inflation Pressure

The inflation pressure will significantly affect the deflection of a tire under load. Therefore the appropriate test inflation pressure must be specified by the requester. Because tires typically operate at a temperature higher than that of the ambient air, operating inflation pressure is usually higher than cold inflation pressure. If the purpose of testing is to simulate the running state, then the inflation pressure used in the test must be equivalent to the on-road operating inflation pressure.

[5] If required, Section 7 of SAE J2429 provides an expanded discussion of the question of calibration in the case of a more complex, but conceptually parallel measuring system.
[6] If required, Section 7 of J2429 provides example possibilities for a more complex, but related measuring system.

9.3 Tire Preparation

Clean the tire surface of dirt, loose material, or other contaminants. Mount the test tire on the tire and rim standards organization specified rim.[7] For rim wheels used on large vehicles such as trucks, tractors, buses, and off-road machines, mounting and demounting shall be done in accordance with the practices specified in (OSHA 1910.177). (OSHA 1910.177) does not apply to the servicing of rim wheels used on automobiles or on pickup trucks and vans utilizing automobile tires or truck tires designated “LT”. The rim used shall meet the specifications noted in Section 6.2.

9.4 Sample Size

Typically, a single tire selected at random from among the group of tires in each specification is an adequate sample if the goal is parametric data for producing a tire model. However, should the desire be to determine differences between tire specifications at a stated level of accuracy it will be necessary to use statistically valid sample sizes and to employ appropriate statistical analyses of the results to define the differences among specifications.

10. Test Procedures

10.1 Prior to Performing Either Procedure

The test tire and rim assembly with the tire properly inflated and prepared for testing shall be mounted on the test machine. The tire shall be carefully loaded until a normal force equivalent to the lesser of 400% of the client specified 100% load or the load at which the rim flange is within 25 mm of the simulated roadway is reached. The lesser of the two loads is the maximum load to be used in these procedures.[8]

10.2 Tire Normal Force/Deflection Procedure

The test tire and rim assembly mounted and inflated in Section 10.1 is now tested. There are two basic ways to run this procedure. Both are described in this section. For either method, appropriate low pass analog filtering shall be applied to prevent aliasing due to high frequencies from contaminating the acquired data. Low frequency oscillations are to be dealt with either through curve fitting or averaging whichever is more appropriate for the test method chosen within the context of the laboratory performing the test.

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[7] The Tire and Rim Association, Inc. is an example of a tire and rim standards organization.
[8] This approach is intended to prevent damage to the test machine, tire cutting by the rim flange, and destruction of the test rim.

10.2.1 INCREMENTAL LOADING METHOD

Divide the maximum allowable load, determined by the pre-experiment defined in Section 10.1, into 10 equal increments. Tare the measuring system. Determine and record the loaded radius at which skim contact exists between the tire and the roadway. In practice, this is the smallest loaded radius that can be achieved before normal force is exerted on the tire by the road.[9] Tare the measuring system. Load the tire to the lowest of the 10 normal force increments. Allow the load to stabilize. Acquire 10 samples of normal force and loaded radius data. Retract the tire to zero normal force. Tare the measuring system. Load the tire to the second lowest of the 10 normal force increments and allow the load to stabilize. Acquire 10 more samples of normal force and loaded radius data. Retract the tire to zero normal force. Repeat the tare/load/acquire data/unload sequence until data have been acquired at all 10 normal force increments. Preserve the normal force and loaded radius data including the skim data in a computer file for data processing.

10.2.2 RAMPED LOADING METHOD

Tare the measuring system. Beginning with the tire slightly out of contact, ramp the loaded radius downward until the maximum allowable load defined in Section 10.1 is reached then retract the tire to the original loaded radius. The ramp shall be completed in between one and three minutes. During ramping data shall be acquired at a rate of at least 25 samples per second. The normal force and loaded radius data acquired during the loading cycle are to be preserved in a computer file ready for data processing.

10.3 Gross Footprint Dimension Procedure

This is a variant of the incremental loading method for determining the tire normal force/deflection behavior. In this practice the contact image measuring system that is specifically discussed is the ink block printing method. Plainly, total internal reflection imaging or a pressure mat system can be substituted subject to the limitations of the system used. To obtain the tire normal force/deflection measurements by the incremental method simultaneously with the production of the footprint images it is only necessary to conduct normal force and loaded radius data acquisition at each imaging condition.

10.3.1 BLOCK PRINTING DESCRIPTION

10.3.1.1 11 pieces of a paper that will not wrinkle under the stresses in the tire contact, for example, posterboard or Bristol board will be prepared for each tire. Each piece of paper shall be larger in size than the largest footprint that is expected. 10 pieces are for printing. The 11th is for use in experimental setup. Each piece is to be labeled with the tire identification.

10.3.1.2 The section of the tire to be printed shall be coated with an appropriate ink or paint.[10]

10.3.1.3 The tire is then pressed against the posterboard at the desired test condition.

10.3.1.4 The tire is retracted after the time that the laboratory has determined to be required to produce a good print, but before appreciable drying of the ink or paint has begun.

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[9] After setting skim, a very small force may exist or the tire may actually clear the surface by a tenth of a millimeter or slightly more.

[10] For example, a foam-rubber stamp pad and stamp pad ink have been found to be adequate to coat the surface.