

Modal Testing and Identification of Lower Order Tire Natural Frequencies of Radial Tires

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1. Scope

This SAE Recommended Practice describes test methods for measuring and identifying the natural frequencies for the **lower order modes** of an inflated radial tire with a fixed spindle while expending modest effort and employing a minimum of test equipment. The methods apply to any size of radial tire so long as the test equipment is properly scaled to conduct the measurements for the intended test tire. Two types of boundary conditions are considered for the tire: **unloaded** and **loaded** against a flat surface. The test involves the performance and measurement of an input vibratory force (excitation) to the tire and the corresponding vibratory output (response). 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 1—The focus of this standard is identification and reporting of the lower order natural frequencies of the tire using a simple test procedure. While higher order natural frequencies may be excited during these tests, the reliable identification of the associated mode shapes is not addressed in this document.

NOTE 2—Herein, road load models are models for predicting forces applied to the vehicle spindles during operation over irregular surfaces, paved or otherwise. Within the context of this document, forces applied to the road or terrain surface are not considered.

1.1 Rationale

This document was developed as part of a set of Recommended Practices intended to allow modelers to determine the parameters required by any of the common tire models for calculating spindle loads given the road surface profile from a single set of experimental results, thus, eliminating duplicate testing.

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

These are available from SAE at 400 Commonwealth Drive, Warrendale, PA 15096-0001, or through the web sight www.sae.org.

SAE J2047—Tire Performance Terminology
SAE J2429—Free-Rolling Cornering Test for Truck and Bus Tires

2.1.2 OTHER PUBLICATIONS

Available in wall chart form as #TTMP-7/95 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 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 document and are either not contained in other Recommended Practices or are worded somewhat differently in this document.

3.1 Unloaded Tire and Associated Coordinate System

The unloaded tire is defined as a tire/wheel assembly attached to a spindle, which is considered to be rigidly supported in both the Radial and Lateral directions. The wheel is locked to prevent rotation about the spindle. The tread is not in contact with any surface. The principal directions are defined in terms of a right-handed cylindrical coordinate system with its origin at the intersection of the spindle and the wheel plane. Three components are defined as follows and illustrated in Figure 1.

3.1.1 TANGENTIAL, T

Tangential displacement is defined in terms of an angle measured about the lateral axis, the centerline of the spindle. It is positive clockwise when looking in the positive lateral direction. The tangential component describes uniform torsional motion of the tread and belt acting as a ring.

3.1.2 LATERAL, L

The lateral axis is directed along the centerline of the spindle. Its origin is in the wheel plane. The positive lateral direction is chosen such that the T-L-R system is a right handed coordinate system.

3.1.3 RADIAL, R

The radial axis is directed outward from the centerline of the spindle in the wheel plane. It is positive moving away from the spindle. It has no preferred angular orientation, but the test engineer must define an orientation so that T has a definite reference.

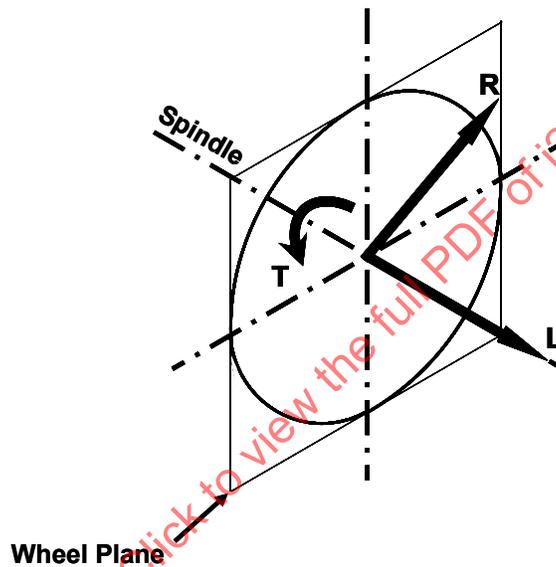


FIGURE 1—CYLINDRICAL COORDINATE SYSTEM USED IN THE UNLOADED CASE

3.2 Loaded Tire and Associated Coordinate System

The loaded tire is defined as a tire/wheel assembly attached to a spindle, which is considered to be rigidly supported in both the Radial and Lateral directions. The wheel is locked to prevent rotation about the spindle. The tire is loaded in contact with the reaction (road) surface so as to produce a tire footprint. The footprint to road surface contact has a no-slip condition. The loaded tire has different natural frequencies and mode shapes than the unloaded tire due to the footprint constraint and the loss of symmetry. Its principal directions are defined in terms of a right-handed Cartesian coordinate system with its origin at the intersection of the spindle and the wheel plane. The three axes are defined as follows and illustrated in Figure 2.

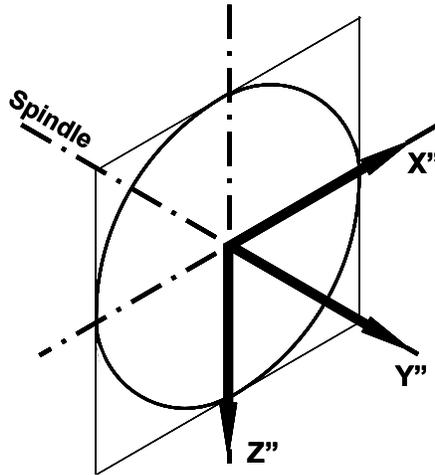


FIGURE 2—THE SAE PARALLEL COORDINATE SYSTEM USED IN THE LOADED CASE

NOTE—In a practical sense it makes no difference which way the tire is mounted since the tire is not rotating. However, for ease of discussion it was assumed that the tire is mounted as if it were on the right front of the vehicle, and as if it were going to move in the positive X'' direction shown in Figure 2.

3.2.1 LONGITUDINAL, X''

The longitudinal axis is parallel to the SAE X' —Axis as defined in J2047. It is positive in the direction indicated in Figure 2.

3.2.2 LATERAL, Y''

The lateral axis is parallel to the SAE Y' —Axis as defined in J2047. Its positive sense is to the right as viewed in the direction of rolling.

NOTE—In the case of a tire without inclination, as assumed in this document, Y'' lies along the spindle center line with a positive sense to the right.

3.2.3 VERTICAL, Z''

The vertical axis is perpendicular to the road plane with a positive sense into the road surface. It is parallel to the SAE Z' —Axis as defined in J2047, but the origin of the vertical axis is at the center of the tire not at the road surface.

NOTE 1—The tire is assumed to have no inclination in this document in which case Z'' lies in the wheel plane.

NOTE 2—Steer motion is understood as a tire mode, which predominantly rotates the tire belt package about the Z'' —Axis.

NOTE 3—Mode shapes and nomenclature are further discussed in Section 4.

3.3 Test

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

3.4 Test Program

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

4. Nomenclature

4.1 Modes of Radial Tires

In this document the modes of radial tires, loaded and unloaded, are categorized as shown in Figure 3. The modes of interest in this document have bold captions in Figure Figure 3. The mode shapes and natural frequencies associated with these modes of vibration are illustrated in Section 10 of this document. (See also SAE 860243.)

NOTE—Lower order mode shapes and their associated natural frequencies are characterized based on the dominant direction of motion of the tire belt package. Motion in the tire symmetry plane² (plane normal to the spindle) is referred to as **in-plane** motion (InP) while motion out of the symmetry plane is **out-of-plane** (OoP).

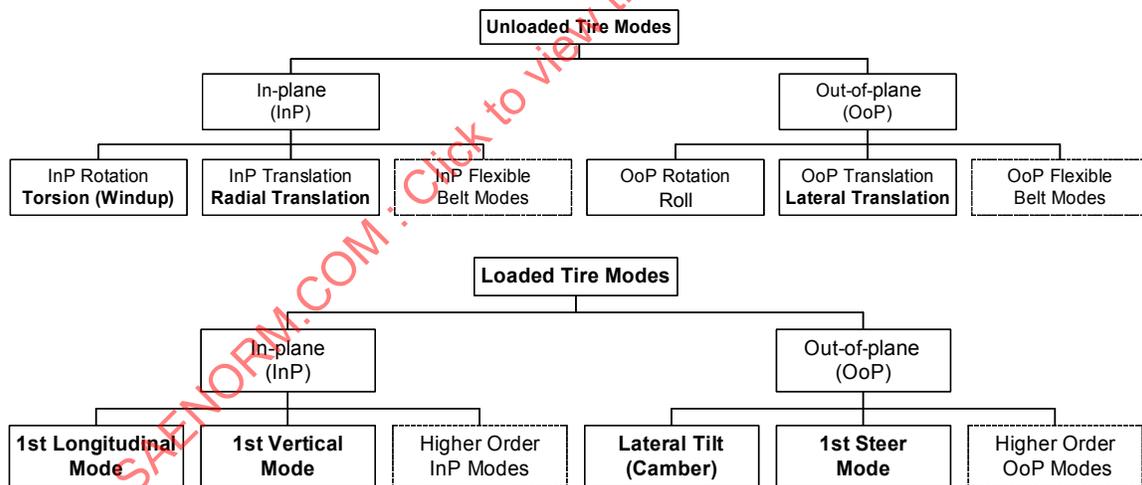


FIGURE 3—TIRE VIBRATION MODES

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 The tire symmetry plane is the R-T plane in the unloaded state and the X"-Z" plane in the loaded state.

4.2 Miscellaneous

For information on items not defined in Section 3 of this document or illustrated within the figures of this section, please see SAE J2047.

5. Laboratory Quality System Requirement

The laboratory performing the procedures specified in this document 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 document.

6. Apparatus

The required apparatus consists of a loading machine / loading fixture, test wheels, standard modal test equipment and instrumentation (an instrumented impact hammer or shaker, accelerometers, power supplies/signal conditioners and analyzer either an integrated device or a data acquisition system coupled to a computer housing appropriate modal analysis software), and miniature light weight blocks and adhesives for mounting modal test transducers on the tire.

6.1 Loading Machine / Loading Fixture

The machine / fixture 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 $22\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$.

6.1.1 LOADING AND POSITIONING SYSTEM

The system shall maintain the tire with the wheel plane within $\pm 0.05^{\circ}$ of perpendicular to the simulated roadway during all loading, a common machine specification when this document was drafted. Loading shall produce normal forces accurate to within $\pm 1.0\%$ 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 the test requester's specified 100% load.

During the loading process, the system must move the tire or the road surface; therefore, it cannot be rigid. It is assumed that during testing that appropriate system elements will lock the spindle to road surface distance and lock the hub in all six degrees-of-freedom.

Machine resonances are a potential problem. They could lead to spurious natural frequencies appearing in the reported data. Ideally, all machine resonances should be at frequencies well above the expected tire natural frequencies. However, this may not be possible.³ Thus, it is recommended that the test machine be evaluated for modes while mounting a metal part simulating the mass and inertia of the tire/wheel assembly to be tested using the procedure described in this document.⁴ This will identify machine resonances that could be a problem.

³ Exact minimum machine resonant frequency recommendations are not made in this Recommended Practice. This was done for two reasons. First, this practice is applicable to all tires regardless of size (wheelbarrow to earthmover) so a single answer is inappropriate. Second, evolving tire designs may alter the required frequencies.

⁴ A disc with a thick outer edge can be used to produce the mass and inertia simulation. The required mass and inertia values can be determined by applying J2717 to the tire/wheel assembly that is to be tested.

NOTE—In the unloaded case, Section 10.3, the tire/wheel assembly could be mounted horizontally on a very short stiff spindle bolted rigidly to a heavy floor slab. The tire's sidewall would barely clear the slab. This arrangement would allow unloaded testing with virtually no concern about machine resonance.

6.1.2 LOAD/DEFLECTION MEASURING SYSTEM

This system shall measure normal force to within $\pm 0.5\%$ of the test machine's full-scale normal force range. The system shall have a normal force range that allows measurement at the client specified 100% load. 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.

The discussion of machine resonances in Section 6.1.1 also applies here.

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. The discussion of machine resonances in Section 6.1.1 also applied here.

6.2 Test Wheels

Test wheels shall meet the dimensional tolerances of original equipment wheels 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—Wheel stiffness may have a discernable influence on the results. Therefore, it is recommended that the test be conducted on a wheel similar in stiffness to the application wheel, if such a test wheel is available.

6.3 Modal Test Vibratory Input Force (Excitation)

The input force to the tire shall be vibratory in nature and shall be achieved by using either an impact hammer, the method described in detail in this document, or an electro-magnetic or electro-hydraulic exciter (shaker). In either case the input signal should contain amplitude content to at least 300 Hz. The location and orientation of the vibratory input force is defined on a per test basis in order to provide appropriate energy to excite the particular natural frequencies (modes) of interest for that test.

NOTE—In the case of shaker excitation, a load cell or impedance head must be attached to the surface of the tire. This is not required when using an impact hammer. The shaker attachment can be accomplished by adhesively mounting a base, similar to an impact block (Section 6.3.2), to the tire using epoxy or hot glue. A “stinger” (threaded rod) is then used to attach the shaker to the load cell or impedance head which is attached to the mounting base. The shaker must be supported so that it is not in contact with any portion of the tire or the test machine. The driving signal to the shaker should have frequency content to beyond 300 Hz. Example input signals are random noise, or burst random noise, or swept sine.

6.3.1 IMPACT HAMMER

In the case of an impact hammer, no mounting technique is required but preparation of the impact surface by use of an impact block may be necessary (Section 6.3.2). An impact hammer contains a load cell for measurement of the impact force. The impact pulse should be verified to be sharp enough to contain measurable signal content to beyond 300 Hz.

Unless otherwise mentioned impact hammer excitation is assumed throughout the remainder of this document.

6.3.2 IMPACT BLOCK

An impact block is a small block attached to the tread surface with an adhesive in order to allow the instrumented hammer's impact force to be conveniently applied parallel to the tread of the tire in the tangential direction.

6.3.2.1 *Impact Block Mass*

The mass of an impact block shall not be large enough to significantly affect modal properties of the tire. In practice the block should weigh less than 0.5% of the weight of the test tire. An impact block should be constructed of a low density rigid material such as aluminum.

6.3.2.2 *Impact Block Size*

Impact blocks should be kept to the minimum size required to fulfill their function. An impact block may be large enough to span more than a single tread block if this is necessary to achieve a good adhesive bond.

6.3.2.3 *Impact Block Mounting*

Impact blocks are attached to the tire at the desired location using a temporary mounting technique such as hot glue or a quick bonding adhesive (superglue or epoxy).

NOTE—If epoxy or superglue type adhesives are used to mount blocks or transducers to the tire, the test sequence specified in this document should be considered destructive and the test tire should not be utilized for dynamic (rotating) tests or on the highway after the test sequence is concluded. The use of hot glue to mount blocks or transducers is not destructive as the glue easily peels from the tire after use.

6.4 Modal Test Vibratory Response Measurement

Accelerometers are to be used to measure the vibratory response of the tire.

6.4.1 ACCELEROMETER FREQUENCY RANGE

Accelerometers should have a minimum natural frequency of 5000 Hz.

6.4.2 ACCELEROMETER MASS

Accelerometer masses shall be small in comparison to the tire mass. This is essential so the presence of an accelerometer will not significantly affect the modal frequencies of the tire. In practice, each accelerometer should have a mass of less than 40 grams.

6.4.3 ACCELEROMETER SIZE

An accelerometer should be smaller than the surface dimension of the tread element to which it is attached. This prevents the accelerometer from overhanging the edge of the tread element.

6.4.4 ACCELEROMETER MOUNTING

6.4.4.1 Allowable Adhesives and Limitations

Test accelerometers are attached to the tire at the desired location using a temporary mounting technique such as hot glue or a quick bonding adhesive (superglue or epoxy).

NOTE—See Section 6.3.2.3 for comments on use of superglue and epoxy.

6.4.4.2 Adhesive Mounting Bases for Accelerometers

If desired an adhesive mounting base may be positioned between the tire and the accelerometer to facilitate mounting the accelerometer. Such bases are subject to the size and mass comments made for impact blocks and accelerometers in Sections 6.3.2.1 and 6.4.2.

6.4.5 MULTIPLE ACCELEROMETERS

Since multiple locations and orientations of the accelerometers are required to complete the testing program, it is acceptable to utilize different accelerometers at different locations and/or accelerometers with multiple active axes at the same location.

6.5 Frequency Limits for Measurements and Analysis

The apparatus shall allow an upper frequency limit of 300 Hz or more combined with a resolution of 0.50 Hz or finer.

6.6 Acceptable Methods of Data Acquisition

Two methods are acceptable. In either case good practice shall be followed to ensure that the test data do not become contaminated due to aliasing, equipment "rattles," low frequency disturbances, cable noise or any other cause.

6.6.1 RECORDING FOR LATER ANALYSIS

The measured force and acceleration signals may be recorded on a Digital Audio Tape (DAT) recorder or similar device and stored for later analysis.

6.6.2 DIRECT ANALYSIS

The measured force and acceleration signals may be presented to a suitable analyzer for immediate analysis.

7. Calibration

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 for the country in which the testing is being performed. Currently valid calibration certificates for reference standards and instruments must be 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

Preparation of the apparatus shall ensure that the test equipment meets its calibration at the outset of each test program. 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 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.

9.3 Tire Preparation

Clean the tire surface of dirt, loose material, or other contaminants. Mount the test tire on a wheel with the tire and rim standards organization specified rim profile.⁵ 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 or on vans utilizing automobile tires or truck tires designated "LT".

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. Modal Test Procedure

As noted in the scope of this document the objective is to correctly identify and report the natural frequencies for the lower order, fixed spindle tire modes in either the loaded and/or unloaded states. In keeping with the desire to achieve this with a minimum investment of time and labor, this test focuses on the impact hammer technique for excitation (See Section 10) while measuring response with a single accelerometer. By carefully choosing accelerometer and impact locations the interpretation of the measured data has been simplified. This was done so as to correctly associate a tire natural frequency with its mode shape, since the order of mode shapes with respect to frequency can vary across tires.

A detailed background on modal testing procedures can be obtained from the book "Modal Testing: Theory, Practice and Application" by Ewins.

10.1 General Guidelines

In the individual elemental tests executed within this total test procedure certain basic practices are followed repetitively as the experiment is repeated successively for each of test locations and directions of impact defined below.

⁵ The Tire and Rim Association, Inc. is an example of a tire and rim standards organization.

The recording device or analyzer is initialized, the pertinent test information is recorded, and the transducer scaling factors and sensitivities are noted. For each test location an impact force is applied to the tire. The transient vibrational response of the tire is measured and allowed to decay before subsequent impacts are applied. Assurance that the response to an impact has ended before another impact is initiated requires that there be several seconds between impacts. The data from a minimum of ten (10) repeated impacts should be recorded and averaged to suppress noise.

NOTE 1—To verify that the input force signal has frequency content to beyond 300 Hz an auto-spectrum calculation should be performed.

NOTE 2—To verify that the response signal is produced by the modal test vibratory input force and not by other spurious input signals a coherence calculation should be performed. The coherence value should be above 0.9 near the observed peaks of the frequency response functions (FRF's).

10.2 Reference Data

Natural frequencies are determined based on frequency-based transfer functions (FRF's) of impact force to acceleration and the phasing of the responses. To make this clear and to give a feeling of the character of real data, example FRF's for Tire B listed in Table 1 are provided with each test procedure. The corresponding modes to be obtained from that test can be determined based on observation of the peaks in the FRF's and of the corresponding phases of multiple responses.

The approximate natural frequencies for the relevant lower modes of the two tires referenced in Table 1 are provided together with representative mode shapes in Figure 4. The mode shapes help illustrate the significance of the excitation and response location(s) and direction(s) for each elemental test, and the corresponding FRF's. The example natural frequencies are for reference only and cannot be relied on as being representative of those for similar tires of the same or approximately equal size because of undefined differences in tire construction and material properties.

TABLE 1—REFERENCE TIRES

Tire	Size	Rim	Inflation Pressure
Tire A	P235/70R17	17x7.5" J	241 kPa
Tire B	P235/45R17		

For purposes of completeness some higher modes are illustrated in Appendix A.

10.3 Modal Test Procedure for the Unloaded Tire (Optional)

The test procedure for the unloaded tire is only executed if specifically requested, however, it is instructional to describe it prior to the loaded tire test procedure. The test procedure for an unloaded tire with a fixed hub requires three different impact tests if a single accelerometer is used and two if two accelerometers are used. The accelerometer mounting and impact locations, as well as representative mode shapes, are identified in Figure 4.

10.3.1 TEST U1—TORSION AND RADIAL TRANSLATION MODES

The location and orientation of the vibratory input for this test excites both the Torsion and Radial Translation modes. When using a single accelerometer this test requires either input excitation at two locations with a response measurement at one location or an input excitation at one location and response measurement at two locations. When using two accelerometers only one excitation location and two response locations are required.

10.3.1.1 *Impact Location and Orientation*

The tire is impacted in the tangential direction at location **A** as indicated in Figure 4. Executing this impact may require the use of an impact block.

10.3.1.2 *Accelerometer Location and Orientation*

An accelerometer is positioned on or near the tread centerline at location **a** as indicated in Figure 4. Its axis of sensitivity is oriented in the tangential direction. If a 2nd accelerometer is available, it is mounted 90° clockwise at location **b** with its axis of sensitivity oriented in the tangential direction.

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☆ Impact location and impact direction

 ■ Accelerometer location and orientation

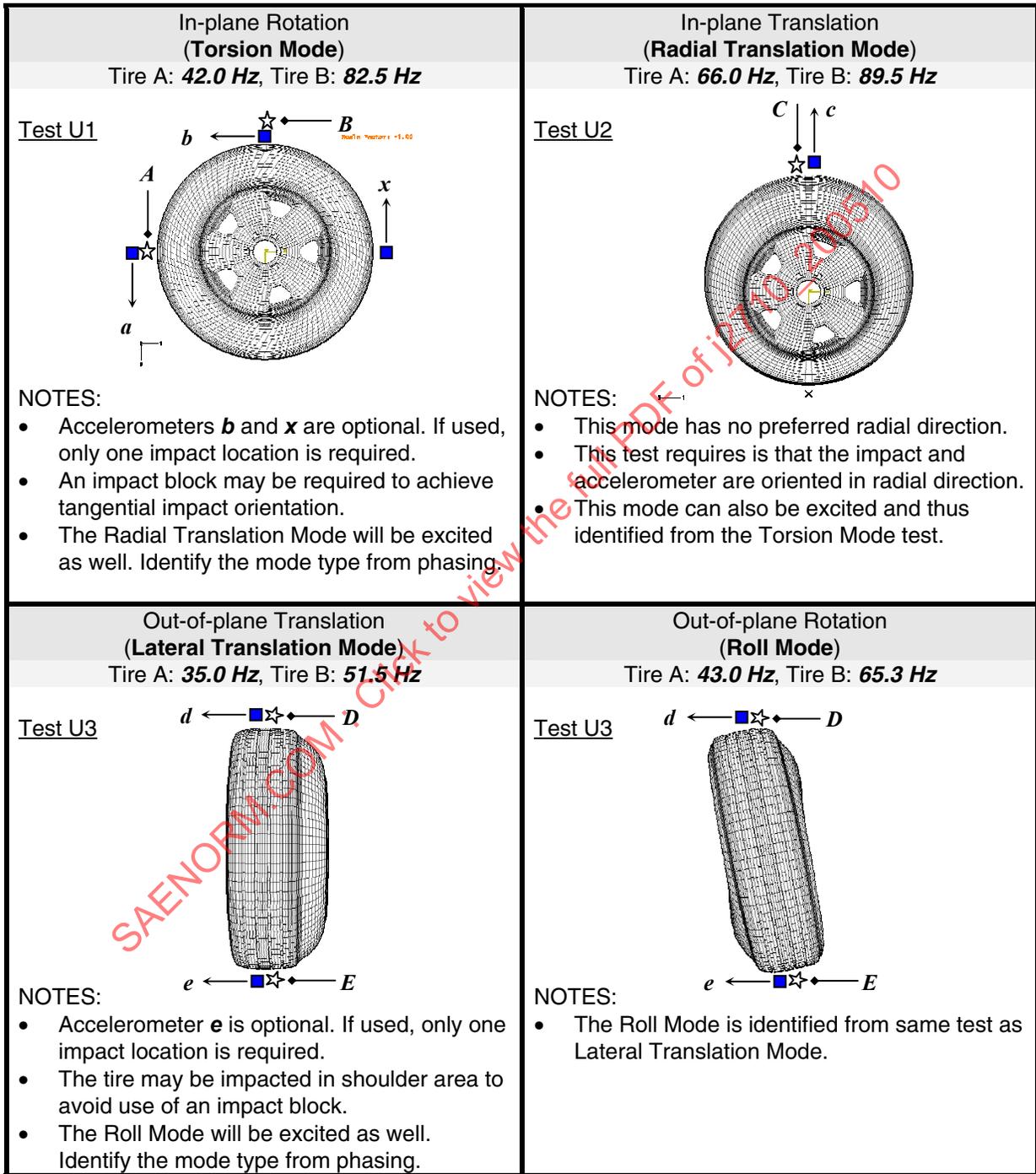


FIGURE 4—UNLOADED TIRE LOWER ORDER VIBRATION MODES

10.3.1.3 Testing with Only One Accelerometer

If using a single accelerometer, change the impact location to **B** (as indicated in Figure 4) and repeat the impact test, or reposition the accelerometer to **b** and change the impact location to **A**.

10.3.1.4 General Conduct of the Impact Test

The impact test is conducted according to the general guidelines presented in Section 10.1.

10.3.1.5 Determining the Torsion and Radial Translation Modes from the Data

The natural frequencies of the Torsion Mode and the Radial Translation Mode are determined by observing the frequency at which the first two peaks occur in the two measured FRF's. The modes are distinguished from each other by observing the phase relationship of those peaks.

As specified location **A** was impacted and responses measured at locations **a** and **b**. The first two closely spaced peaks in the **a/A** FRF shown in Figure 5 and the first peak in the **b/A** FRF shown in Figure 6 provide the frequencies of the Torsion Mode and the Radial Translation Mode.

To distinguish the modes the **b/A** FRF is used. Because **b** is located 90° from the **A** excitation, ideally only the tangential motion of the Torsion Mode can be seen. Therefore a single peak is seen in the **b/A** FRF at 82.5 Hz. This is the Torsion Mode. Confirmation can be made by comparing the phases at this frequency. The phase difference between **a/A** and **b/A** is 31°. In experimental terms, this phase difference is considered to be close to 0° and therefore defines in-phase motion. (See Section 11 for further discussion.) The second peak on the **a/A** FRF at 89.5 Hz is the Radial Translation Mode. (Note that there is not a peak at this frequency in the **b/A** FRF.)

10.3.1.6 An Optional Accelerometer Location

The second accelerometer may be mounted 180° offset at location **x** instead of or in addition to location **b**. As with accelerometer **a**, the **x/A** FRF will contain peaks for both Torsion and Radial Translation Modes. This location is mentioned should it prove advantageous in a particular experimental setup.

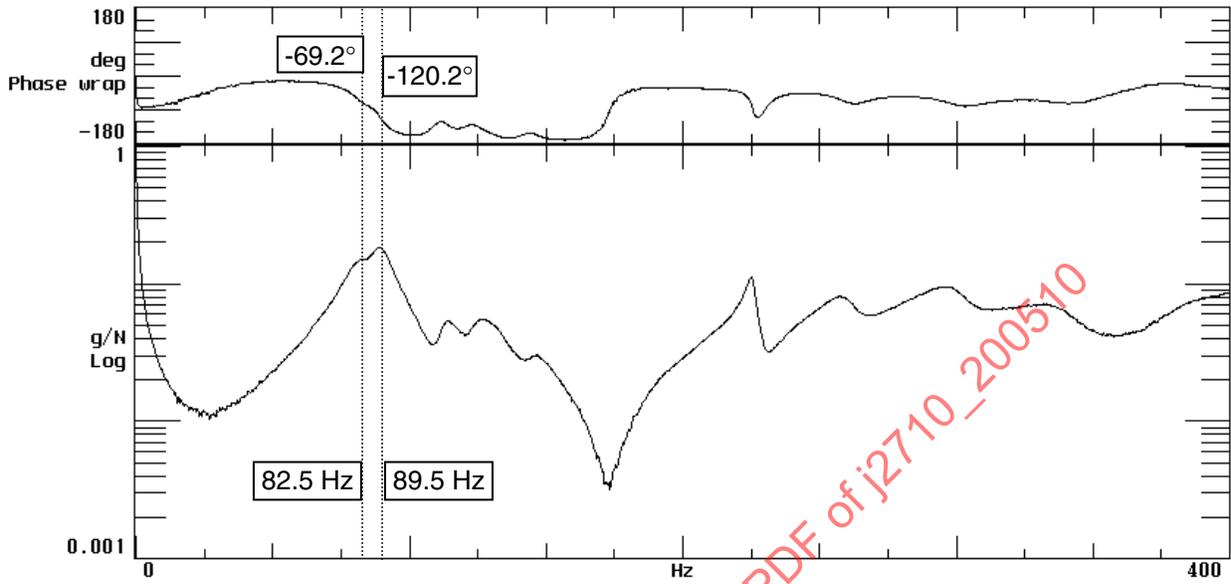


FIGURE 5—TEST U1 - FRF OF ACCELERATION AT *a* DUE TO IMPACT AT *A*

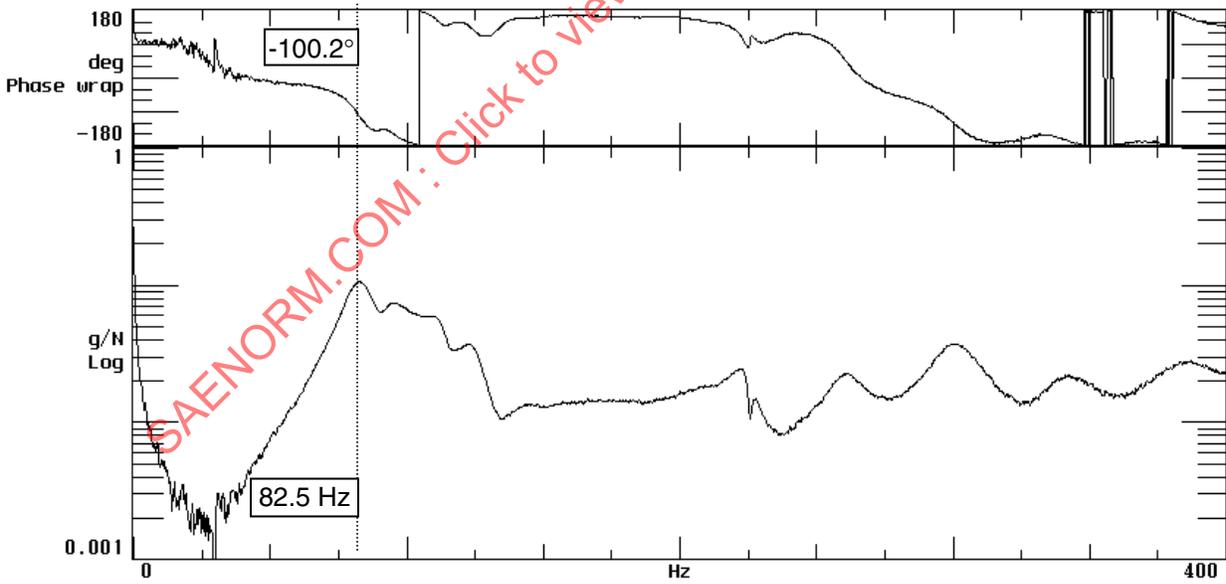


FIGURE 6—TEST U1 - FRF OF ACCELERATION AT *b* DUE TO IMPACT AT *A*

10.3.2 TEST U2 – RADIAL TRANSLATION MODE

This test is optional. It is designed to excite only the Radial Translation Mode and NOT the Torsion Mode. It can also be used to confirm or distinguish the natural frequency of the Radial Translation Mode from that of the Torsion Mode. Both can be identified from Test U1.

10.3.2.1 Impact Location and Orientation

The tire is impacted in the radial direction at location **C** as indicated in Figure 4.

10.3.2.2 Accelerometer Location and Orientation

An accelerometer is positioned on or near the tread centerline at location **c** as indicated in Figure 4. Its axis of sensitivity is oriented in the radial direction.

10.3.2.3 General Conduct of the Impact Test

The impact test is conducted according to the general guidelines presented in Section 10.1.

10.3.2.4 Determining the Radial Translation Mode Frequency

The natural frequency of the Radial Translation Mode is determined by observing the frequency at which the first peak occurs in the measured **c/C** FRF. An example **c/C** FRF is provided in Figure 7. The first peak at 89.5 Hz is the Radial Translation Mode.

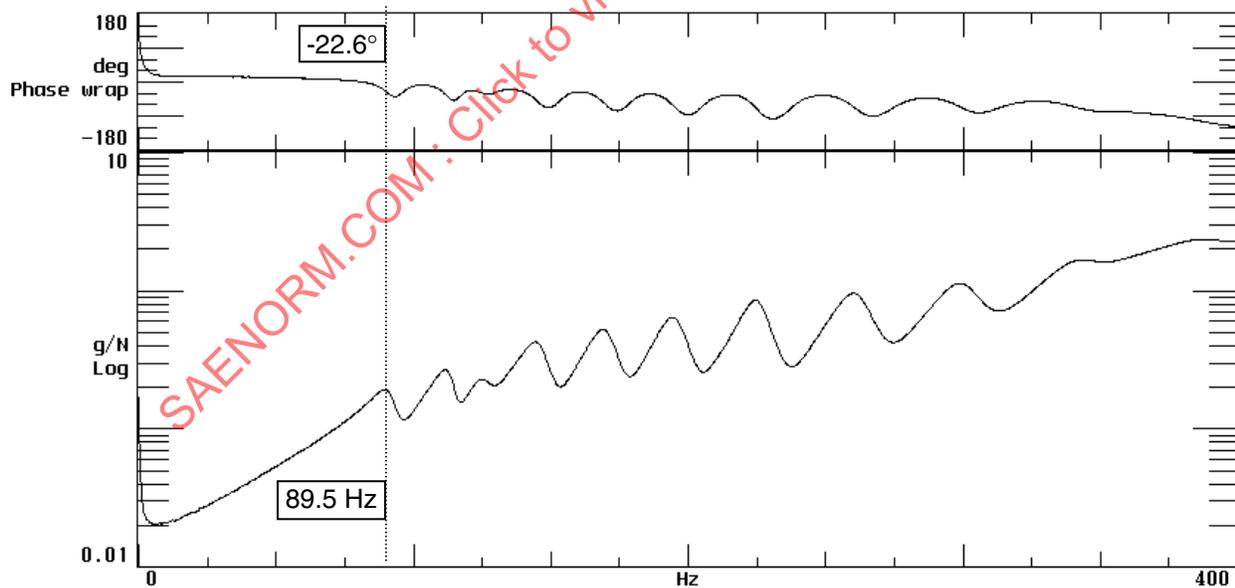


FIGURE 7—TEST U2 - FRF OF ACCELERATION AT **c** DUE TO IMPACT AT **C**

10.3.3 TEST U3 – LATERAL TRANSLATION AND ROLL MODES

The location and orientation of the vibratory input for this test excites both the Lateral Translation and Roll Modes. When using a single accelerometer this test requires either input excitation at two locations with a response measurement at one location or an input excitation at one location and response measurement at two locations. When using two accelerometers only one excitation location and two response locations are required.

10.3.3.1 Impact Location and Orientation

The tire is impacted in the lateral direction at location **D** as indicated in Figure 4. Executing this impact may require the use of an impact block or it may be possible to impact the tire on the shoulder.

10.3.3.2 Accelerometer Location and Orientation

An accelerometer is positioned on or near the tread centerline at location **d** as indicated in Figure 4. Its axis of sensitivity is oriented in the lateral direction. If a 2nd accelerometer is available, it is mounted 180° away at location **e** with its axis of sensitivity in the lateral direction.

10.3.3.3 Testing with Only One Accelerometer

If using a single accelerometer, change the impact location to **E** (as indicated in Figure 4) and repeat the impact test, or reposition the accelerometer to **e** and change the impact location to **D**.

10.3.3.4 General Conduct of the Test

The impact test is conducted in accordance with the general guidelines presented in Section 10.1.

10.3.3.5 Determining the Lateral Translation and Roll Modes from the Data

The natural frequencies of the Lateral Translation and Roll Modes are determined by observing the frequency at which the first two peaks occur in the two measured FRF's. The two modes are distinguished by observing the corresponding phase relationship at those peaks.

As specified location **D** was impacted and responses measured at **d** and **e**. The first two peaks in the **d/D** FRF shown in Figure 8 and the **e/D** FRF shown in Figure 9 provide the frequencies of the Lateral Translation and Roll Modes. To distinguish the modes, the phase differences are considered. In-phase behavior at **d** and **e** is characteristic of the Lateral Translation Mode. Out-of-phase behavior is characteristic of the Roll Mode.

The first peak occurs at 51.5 Hz. The phase difference between **d** and **e** is 24.3°. In experimental terms, this phase difference is considered to be close to 0° and, therefore, represents in-phase motion. (See section 11 for further discussion.) Therefore, this peak defines the Lateral Translation Mode natural frequency.

The second peak occurs at 65.3 Hz. The phase difference between **d** and **e** is 187.4°. In experimental terms, this phase difference is considered to be close to 180° and, therefore, represents out-of-phase motion. (See Section 11 for further discussion.) Therefore, this peak defines the Roll Mode natural frequency.

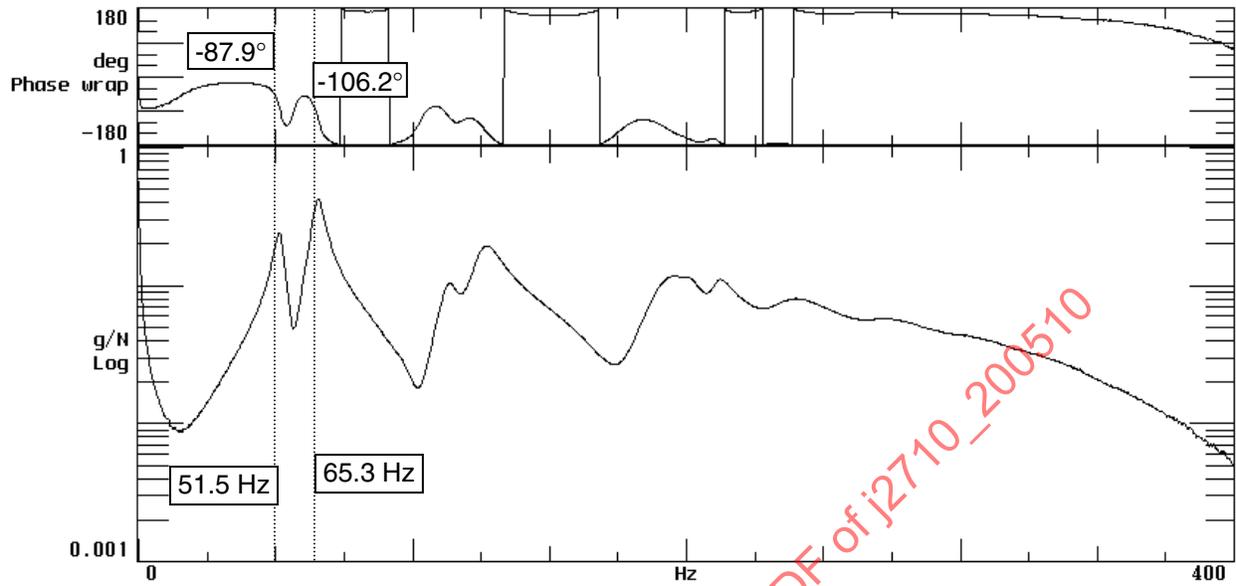


FIGURE 8—TEST U3 - FRF OF ACCELERATION AT *d* DUE TO IMPACT AT *D*

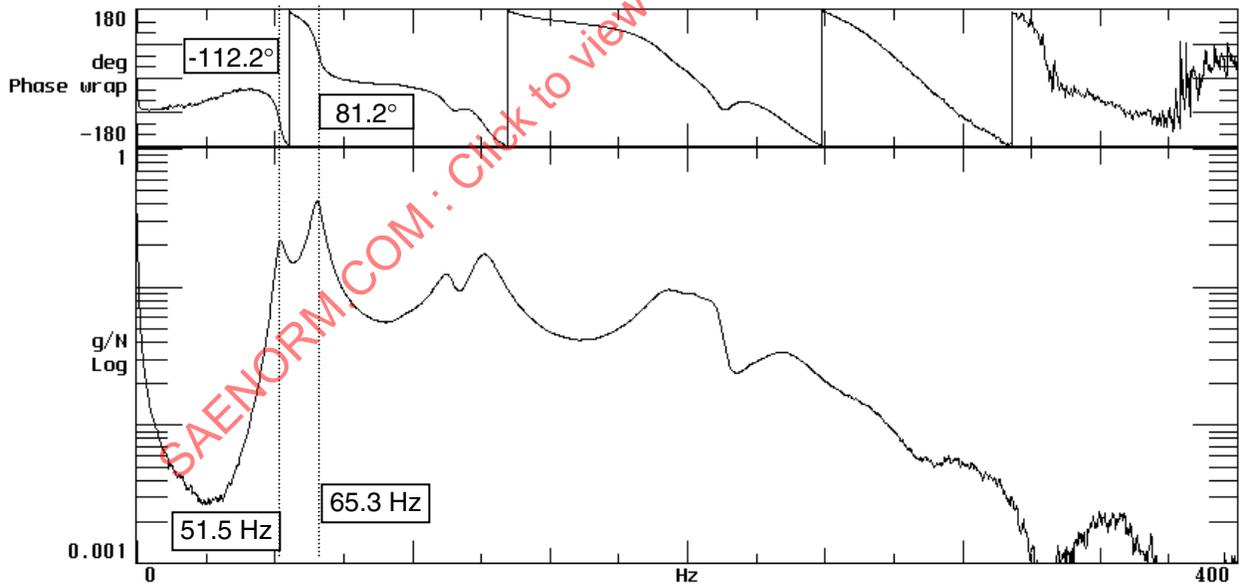


FIGURE 9—TEST U3 - FRF OF ACCELERATION AT *e* DUE TO IMPACT AT *D*

10.4 Modal Test Procedure for the Loaded Tire

The test procedure for a loaded tire with a fixed hub requires four different impact tests if a single accelerometer is used and three if two accelerometers are used. The accelerometer mounting and impact locations are identified in Figure 10.

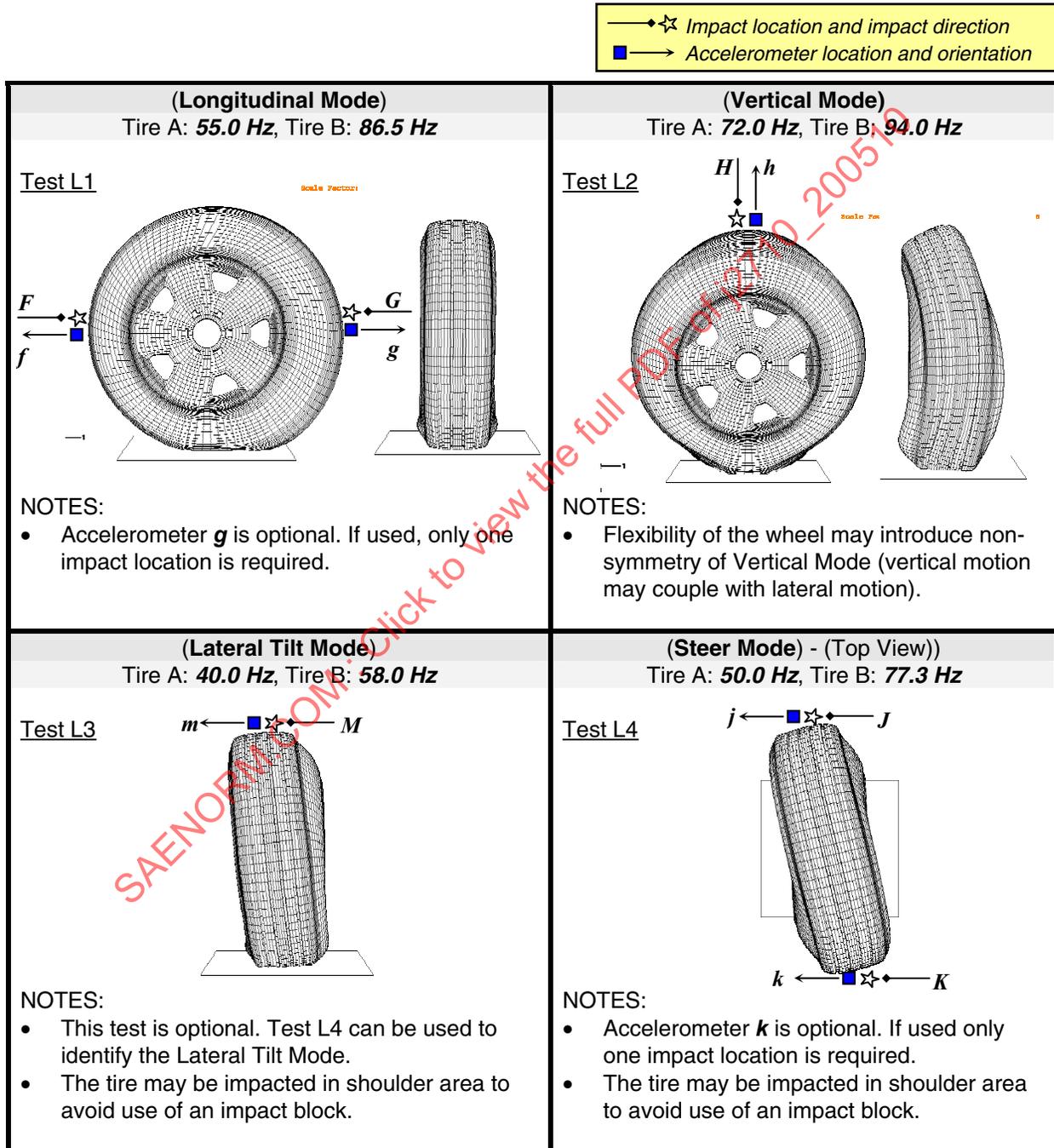


FIGURE 10—LOADED TIRE LOWER ORDER VIBRATION MODES

10.4.1 TEST L1 – LONGITUDINAL MODE

This test is designed to determine the natural frequency of the first Longitudinal Mode.

10.4.1.1 *Impact Location and Orientation*

The tire is impacted in the longitudinal direction at location **F** as indicated in Figure 10.

10.4.1.2 *Accelerometer Location and Orientation*

An accelerometer is positioned on or near the tread centerline at location **f** as indicated in Figure 10. Its axis of sensitivity is oriented in the longitudinal direction. If a 2nd accelerometer is available, it is mounted 180° offset at location **g** with its axis of sensitivity oriented in the longitudinal direction.

10.4.1.3 *Testing with Only One Accelerometer*

If using a single accelerometer, then reposition the accelerometer to **g** (as indicated in Figure 10) or change the impact location to **G** and repeat the test.

10.4.1.4 *General Conduct of the Impact Test*

The impact test is conducted according to the general guidelines presented in Section 10.1.

10.4.1.5 *Determining the Longitudinal Mode from the Data*

The natural frequency of the Longitudinal Mode is determined by observing the frequency at which the first peak occurs in the two measured FRF's. The mode can be verified by observing the corresponding phase relationship at the observed first peak of two FRF's.

As specified location **F** was impacted and responses measured at **f** and **g**. The lowest peak in the **f/F** response shown in Figure 11 and more evident in the **g/F** response shown in Figure 12 provide the frequency of the Longitudinal Mode. Confirmation that these peaks represent the Longitudinal Mode can be obtained by comparing the FRF phases at this frequency. Because the response accelerometer positive response directions are oriented 180° from each other, the response phases are added. The phase difference is 76° which is less than 90° and therefore considered in-phase motion. (See Section 11 for further discussion.)

10.4.2 TEST L2 – VERTICAL MODE

This test is designed to determine the natural frequency of the first Vertical Mode.

10.4.2.1 *Impact Location and Direction*

The tire is impacted in the vertical direction at location **H** as indicated in Figure 10.

10.4.2.2 *Accelerometer Location and Orientation*

An accelerometer is positioned on or near the tread centerline at location **h** as indicated in Figure 10. Its axis of sensitivity is oriented in the vertical direction.

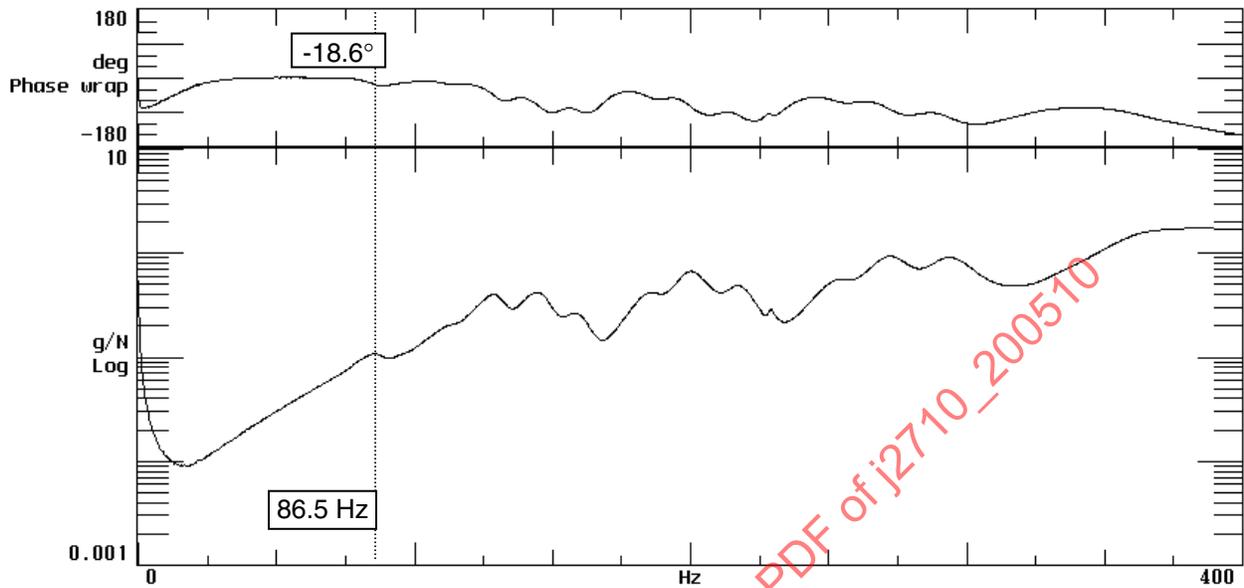


FIGURE 11—TEST L1 - FRF OF ACCELERATION AT f DUE TO IMPACT AT F

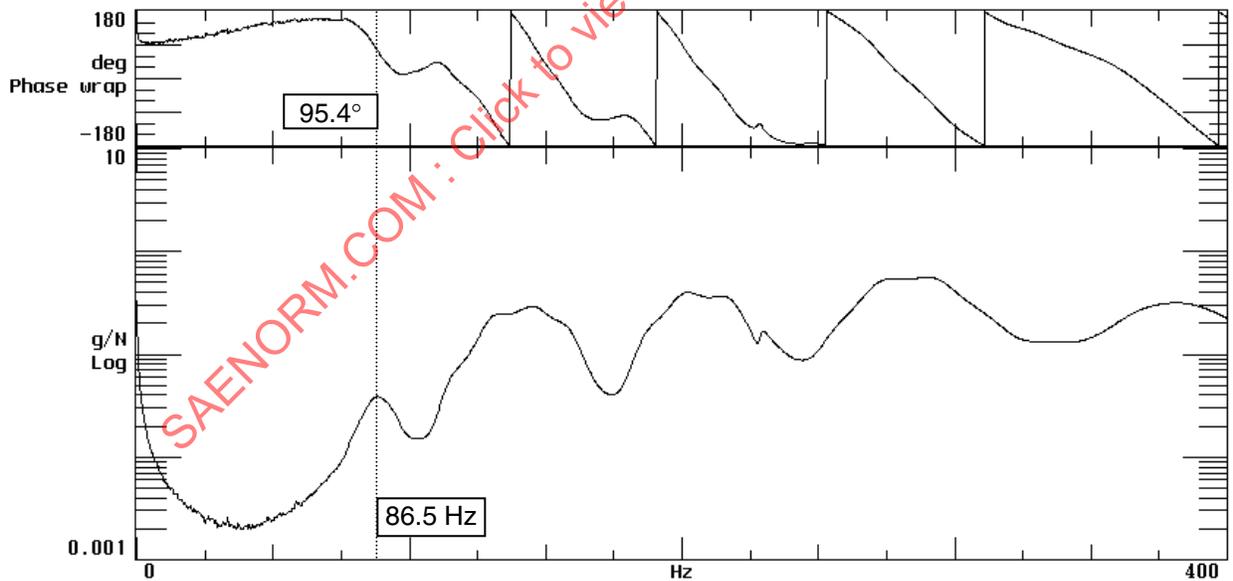


FIGURE 12—TEST L1 - FRF OF ACCELERATION AT g DUE TO IMPACT AT F

10.4.2.3 General Conduct of the Impact Test

The impact test is conducted according to the general guidelines presented in Section 10.1.

10.4.2.4 Determining the Vertical Modal Natural Frequency

The natural frequency of the Vertical Mode is determined by observing the frequency at which the first peak occurs in the h/H FRF. An example h/H FRF is provided in Figure 13. The first peak at 94.0 Hz is the Vertical Mode.

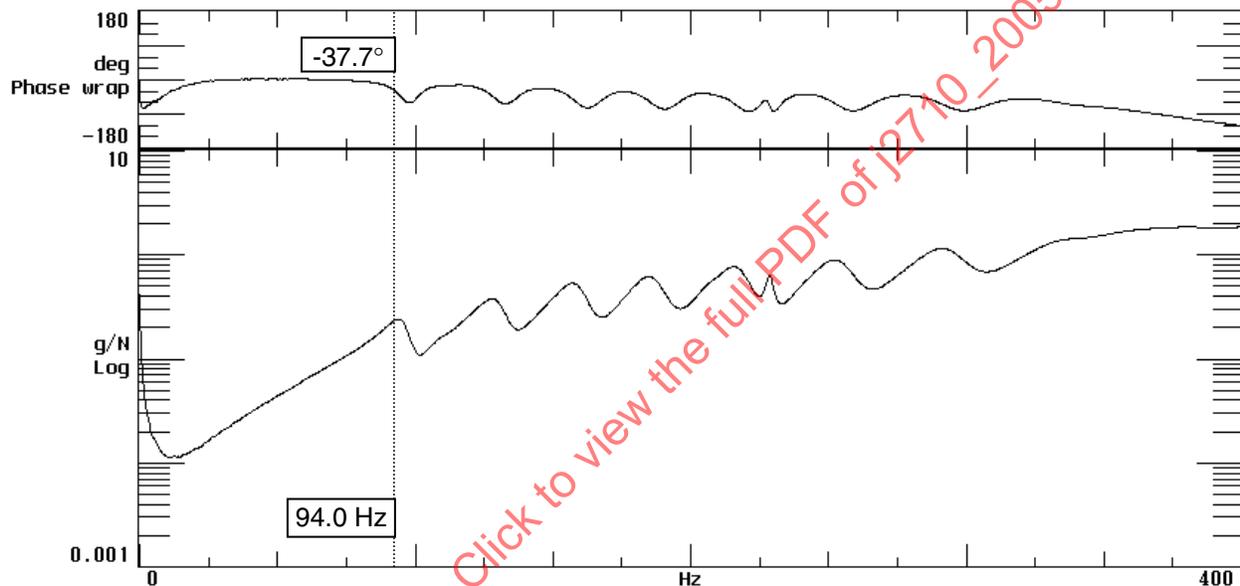


FIGURE 13—TEST L2 - FRF OF ACCELERATION AT h DUE TO IMPACT AT H

10.4.3 TEST L3—LATERAL TILT MODE (OPTIONAL)

This test is optional, since the Lateral Tilt Mode can be identified from Test L4. It is designed to excite only the Lateral Tilt Mode.

10.4.3.1 Impact Location and Direction

The tire is impacted in the lateral direction at location M as indicated in Figure 10 or alternatively when possible laterally on the shoulder at the top of the tire. An impact block may be required to impact the tire in the lateral direction at location M .

10.4.3.2 Accelerometer Location and Orientation

An accelerometer is positioned on or near the tread centerline on the top of the tire at location m as indicated in Figure 10. Its axis of sensitivity is oriented in the lateral direction.