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Standard Practice for Measuring the Dynamic Characteristics of Amusement Rides and Devices[1]

This standard is issued under the fixed designation F2137; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers acquisition of data related to the dynamic characteristics of amusement rides and devices.

1.2 This practice also defines the specific requirements of a Standardized Amusement Ride Characterization Test (SARC Test) for use in characterizing the dynamic motion of an amusement ride or device.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3.1 *Exception*—The values are reversed in Section 13 since EN standards primarily use SI units.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F747 Terminology Relating to Amusement Rides and Devices

2.2 *SAE Standard:*[3]

SAE J211 Instrumentation for Impact Tests

2.3 *EN Standard:*[4]

EN 13814 Fairground and amusement park machinery and structures - Safety

3. Terminology

3.1 *Definitions:*

3.1.1 *aliasing*—a phenomenon associated with sampled data systems, wherein a signal containing significant energy at frequencies greater than one half of the system sample frequency manifests itself in the sampled data as a lower frequency (aliased) signal. Aliasing can be avoided only by limiting the frequency content of the signal prior to the sampling process. Once a signal has been aliased, it is not possible to reconstruct the original signal from the sampled data.

3.1.2 *calibration constant*—the arithmetic mean of the sensitivity coefficients, evaluated at frequencies that are evenly spaced on a logarithmic scale between F_L and F_H.

3.1.3 *calibration value*—the ratio of the reference calibration system output, in engineering units relevant to the transducer, to the data channel output, in volts, as measured at constant excitation frequency and amplitude.

3.1.4 *channel frequency class (CFC)*—a frequency response envelope that conforms to Fig. 1 and is referred to by the value F_H in hertz. The CFC frequency response envelope is defined by the boundaries shown in Fig. 1 and the following characteristic frequencies:

F_L—Pass band lower limit (hertz). Always equal to zero (0.0) hertz.

F_H—Pass band upper limit (hertz). The CFC designator.

F_N—The corner or knee of the frequency response envelope. Always equal to or greater than $1.667 \times F_H$.

F_S—The minimum sample frequency for a sampled data system that corresponds to the designated CFC. Always equal to or greater than $12 \times F_H$.

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[1] This practice is under the jurisdiction of ASTM Committee F24 on Amusement Rides and Devices and is the direct responsibility of Subcommittee F24.10 on Test Methods.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

[4] Available from European Committee for Standardization, http://www.cen.eu/.

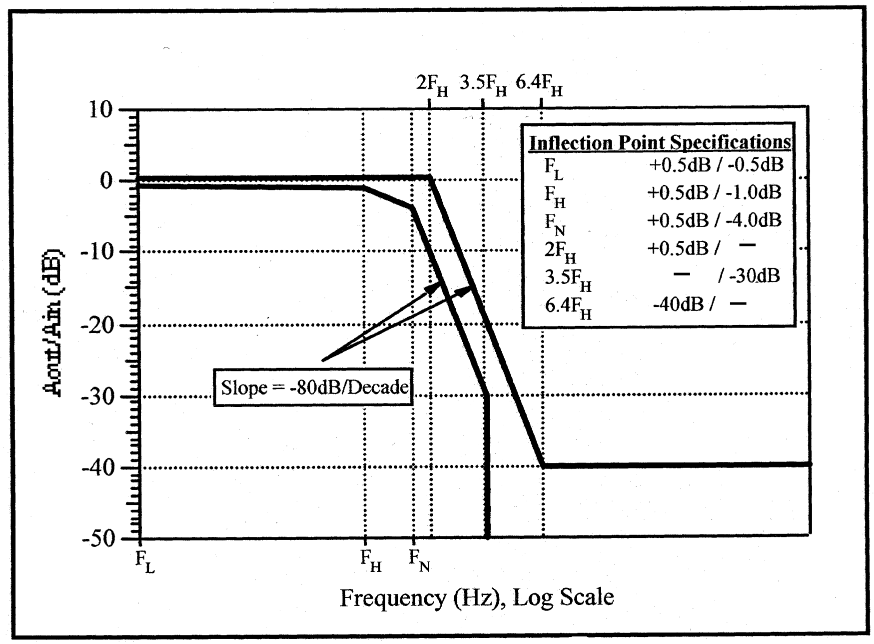

FIG. 1 Frequency Response Envelope

3.1.4.1 *Discussion—*

F_L,F_H,F_N, and F_S are always specified in hertz. While the characteristics of the CFC may be applied to individual components of a data channel, the CFC is, by definition, the frequency response envelope of the entire data channel from the mounted transducer to the final representation of the acquired data.

3.1.5 *coordinate system*—three orthogonal axes that intersect at an origin whose positive directions correspond to the right-hand rule.

3.1.5.1 *measurement coordinate system*—a coordinate system that provides the reference axes and sign convention for the test data record(s).

3.1.5.2 *patron coordinate system*—a coordinate system that is fixed with respect to the human upper torso and oriented as in Fig. 2.

3.1.5.3 *vehicle coordinate system*—a coordinate system that is fixed with respect to the ride or device being tested.

3.1.6 *data channel*—the entire instrumentation system for a single channel of data acquisition; from the transducer to the final representation of the data, including all post-acquisition data processing that may alter the amplitude or frequency content of the data.

3.1.7 *data channel full scale*—the maximum usable value, in units of the physical phenomenon being measured, that may be represented by a data channel. This value is determined by the data channel component with the lowest full-scale range.

3.1.8 *free-run time*—a period of time during the ride cycle when no energy is added to the ride vehicle.

3.1.9 *full-scale*—the maximum usable value, in units of the physical phenomenon being measured, which may be represented by a data channel or some component thereof.

3.1.10 *"g"*—the standard acceleration due to gravity at the surface of the earth. Defined as 32.2 ft/s/s or 9.81 m/s/s.

3.1.11 *nonlinearity*—the ratio, in percent, of the maximum difference between a calibration value and the corresponding value determined from the straight line defined by the sensitivity coefficient and zero bias.

3.1.12 *reference calibration system*—the entire calibration instrumentation system from the reference transducer to the output device that provides the calibration excitation value in engineering units appropriate to the physical phenomenon being measured.

3.1.13 *resolution*—the lowest magnitude data channel output value that can be identified as non-zero.

3.1.14 *sensitivity coefficient*—the slope of the straight line representing the best fit, as determined by the method of least squares, to calibration values generated at a single frequency and at various amplitudes within the data channel full scale range. In the special case where only a single calibration value is considered, the sensitivity coefficient and the calibration value will be equal.

3.1.15 *standardized amusement ride characterization test (SARC Test)*—an instrumented test of an amusement ride or device that is done in conformance to the general specifications of this standard and the particular specifications of Section 12.

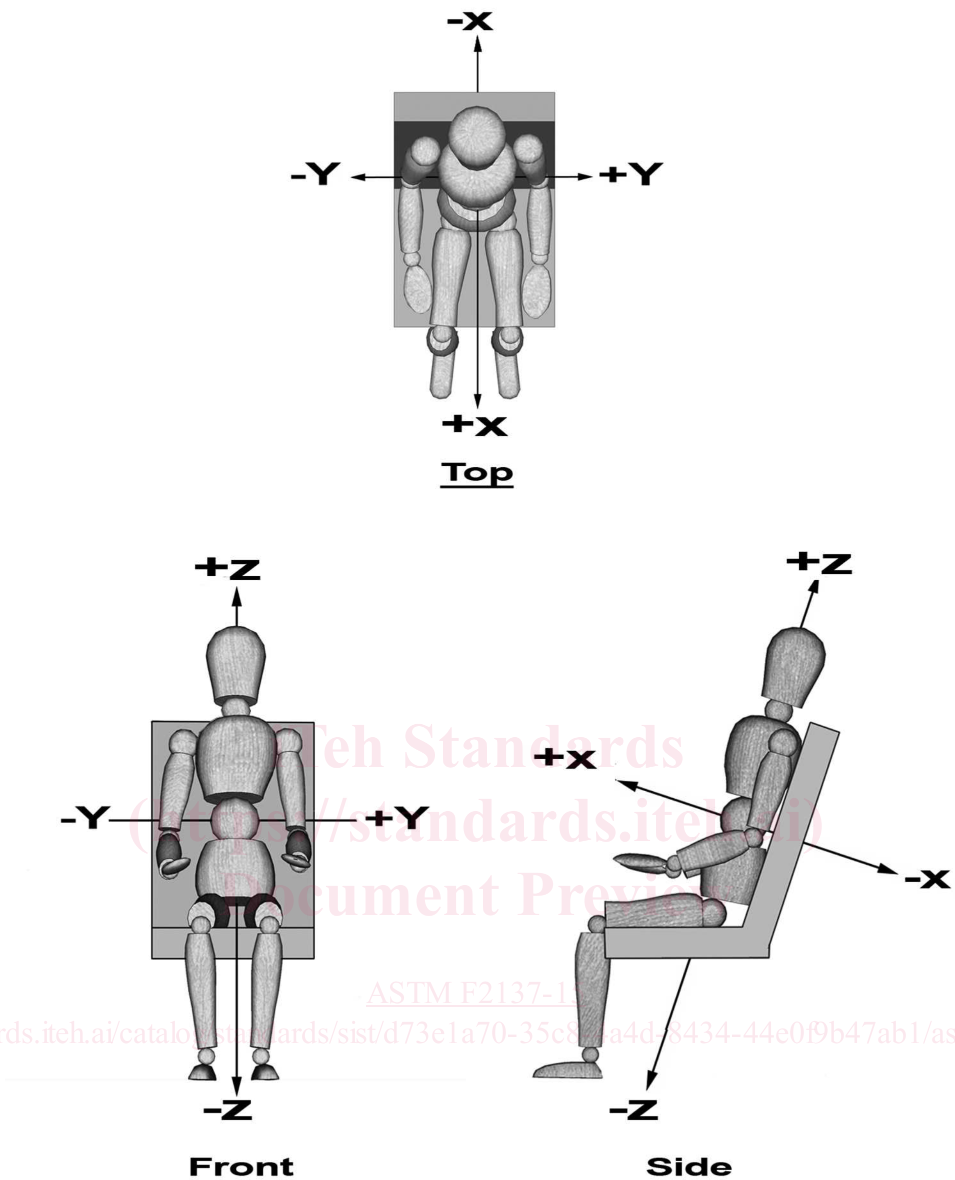

FIG. 2 Patron Coordinate System

3.1.16 *test data record*—the uninterrupted time record of data channel value(s) that results from a data acquisition session. the length of a data acquisition session is not specified. The data acquisition session is considered complete (or interrupted) when data is not recorded for a time interval longer than the sampling period of the data recorder. Both a strip chart paper record and a computer data file containing periodically sampled data channel values are typical forms of a test data record.

3.1.17 *test documentation*—the entire body of documentation pertaining to a test performed in compliance with this practice, including, but not limited to, the test data record(s), data channel specifications and other test specifications, and information as provided in this practice (see Section 11 and 12.1.9).

3.1.18 *transducer*—the device at the front end of the data channel that converts a physical phenomenon, such as acceleration, to a calibrated electrical signal that may be input to the remainder of the data channel.

3.1.19 *transverse sensitivity*—the sensitivity of a rectilinear transducer to excitation along an axis that is perpendicular to its nominal sensitive axis.

3.1.20 *zero bias*—the magnitude of the data channel output when the transducer input is zero or static.

4. Significance and Use

4.1 This practice is intended for use whenever the dynamic characteristics of an amusement ride or device are to be determined. The existence of this practice is not intended to imply that there is a requirement to perform specific testing on amusement rides or devices.

4.2 The general provisions of this practice provide instrumentation specifications, data acquisition and testing procedures, and documentation requirements that when applied will improve the repeatability, reliability, and utility of the test results.

4.3 Based on the general provisions of this practice, the SARC Test specifications, when followed, will yield standardized test results regarding the patron-related, dynamic motion of amusement rides or devices. The SARC Test will facilitate both the meaningful comparison of the dynamic motion of different amusement rides or devices and the tracking of changes, if any, in the dynamic characteristics of a given ride or device.

5. Data Channel Performance Specifications

5.1 *CFC Definitions*—The following channel frequency classes are defined as standard:

	CFC10[A]	CFC60[B]
F_L	0.0 Hz	0.0 Hz
F_H	10.0 Hz	60.0 Hz
F_N	16.7 Hz	100 Hz
F_S	120 Hz	720 Hz

[A] CFC10 should be used when the data channel is being used for acquisition of lower frequency events.
[B] CFC60 should be used when the data channel is being used for acquisition of higher frequency events.

Other channel frequency classes may be defined as needed or desired by the user of this practice. The proportional relationship between F_H,F_N , and F_S shall be maintained for all channel frequency classes.

5.2 Minimum data channel resolution shall be 2 % of the data channel full scale.

5.3 Maximum nonlinearity shall be 2.5 % of the data channel full scale.

5.4 Minimum time base resolution shall be $1/F_S$ (s).

5.5 Maximum relative delay or time shift between data channels that are nominally acquired simultaneously shall be $1/F_S$ (s).

6. Transducer Performance Specifications

6.1 Transducer selection shall be consistent with the intended test objectives and generally accepted instrumentation and engineering practice.

6.2 The transducer frequency response curve shall conform to the CFC frequency response envelope from F_L through $2 \times F_H$ and exhibit no more than +6 dB of peaking at the natural frequency of the transducer.

6.3 Maximum transverse sensitivity shall be 3 %.

7. Recorder Performance Specifications

7.1 *Analog Data Recorders:*

7.1.1 The analog data recorder shall provide a method by which the zero bias, if any, can be reduced to less than the data channel minimum resolution prior to acquiring any test data.

7.1.2 Minimum amplitude resolution shall be two 2 % of the data channel full scale.

7.1.3 Paper tape recorders (or their equivalent) shall provide a minimum paper speed, in mm/s, of $1.5 \times F_H$ (Hz).

7.2 *Digital Data Recorders:*

7.2.1 All data shall be acquired with a minimum CFC of ten.

7.2.2 Minimum amplitude resolution shall be 0.10 % of the data channel full scale.

7.2.3 Minimum sample rate shall be F_S (Hz) for the chosen CFC.

7.2.4 Protection from aliasing errors in the sampled data shall be accomplished by pre-sample filtering that conforms to the specified CFC frequency response envelope for the data channel.

7.2.4.1 Alternate protection from aliasing errors may be accomplished by providing appropriate pre-sample, anti-alias filtering in conjunction with a higher-than-F_S sample rate and digital post-acquisition filtering such that the frequency response envelope of the data channel conforms to the desired CFC frequency response envelope. The anti-alias filter characteristics shall be such that the maximum possible signal amplitude at one half the sampling frequency is less than the data channel minimum resolution.

8. Calibration Specifications

8.1 For transducers, data recorders, or any other data channel component that is subject to calibration changes over time, the calibration constant and frequency response shall be determined and documented annually.

8.2 Reference calibration instrumentation used as a secondary standard in the calibration of a data channel or any subsystem thereof shall have current certificates of calibration that are traceable to accepted national standards.

8.3 The reference calibration system and calibration methods shall not introduce a calibration error greater than 1.5 % of the data channel full scale.

8.4 To establish a data channel or data channel component frequency response and calibration constant, sensitivity coefficients shall be determined from calibration values measured at a minimum of one signal amplitude that represents at least 50 % of the full scale range of the data channel or component being calibrated and throughout a range of frequencies from F_L to $10 \times F_H$ for a given CFC. A minimum set of five sensitivity coefficients establishes the frequency response of a data channel or component. The minimum set of sensitivity coefficients shall be generated at frequencies that nominally correspond to the following CFC specifications:

$$F_L, F_H, F_N, 2 \times F_H, \text{and } 10 \times F_N$$

8.5 To establish nonlinearity, a minimum of one sensitivity coefficient shall be determined from calibration values generated at a minimum of three signal amplitudes that nominally correspond to the following percentages of the minimum full-scale range of the data channel or data channel component being calibrated: Less than 20 % of full scale, 50 % of full scale, and >80 % of full scale. For the minimum requirement of a single sensitivity coefficient, the nominal frequency shall be halfway between F_L and F_H.

9. Transducer Location and Mounting

9.1 *General Instrumentation:*

9.1.1 Transducer location, orientation, and mounting method shall be consistent with the intended test objectives and generally accepted instrumentation and engineering practice.

9.1.2 Transducers shall be mounted such that the angle between the sensitive axis (axes) of the transducer and the corresponding axis (axes) of the selected coordinate system shall be no greater than 5°.

9.2 *General Accelerometry:*

9.2.1 *Mounting*—To avoid distortion in the data channel values, accelerometers shall be mounted so as to minimize relative motion between the transducers and the instrumented surface. When deemed appropriate, an analytical or experimental evaluation of transducer mounting effects on the data channel should be provided (see 11.1.6).

9.2.2 When multi-axis accelerations at a point are to be measured, the center of seismic mass of each accelerometer shall be within 60 mm of that point. Each accelerometer axis shall be within one degree of orthogonal relative to the other axes.

10. Procedure

10.1 The unique characteristics of a particular amusement ride or device or other special circumstances may be such that it is not reasonably possible to test in strict conformance with one or more provisions of this practice. Any deviation(s) from the provisions of this practice shall be recorded so as to clearly provide a description of the specific deviation(s).

10.2 *Field Calibration:*

10.2.1 Where practical, all data channels should be subjected to a field calibration procedure to establish the reliability of the data channel calibration.

10.2.2 For accelerometer-based data channels, the field calibration procedure, may take the form of a 2*g* "roll-over" test. The 2 *g* "roll-over" test requires that the accelerometer be placed with its sensitive axis perpendicular to a plane surface that is nominally level with respect to the earth while the output of the data channel is recorded. The accelerometer should then be oriented with its sensitive axis parallel to this surface to record a zero-*g* input. Next, the accelerometer should be inverted with respect to its original orientation and its output recorded. This procedure will yield a three-point calibration (+1*g*, 0*g*, and -1*g*) with a nominal 2*g* range.

10.3 When testing the nominal dynamic characteristics of amusement rides and devices that have characteristics that change with respect to operating temperature, the rides or devices shall be operated for a minimum of three full cycles prior to data collection. Additionally, in the case of gravity operated amusement rides or devices, such as roller coasters, the rides or devices should be operated until free-run times have a variability of less than 5 % prior to data collection.

10.4 The zero bias of each data channel shall be accounted for in the test data record(s).

11. Test Documentation

11.1 Include the following in the test documentation:

11.1.1 General test information, including but not limited to ride or device name, serial number, and location; test date and time; and the names of the testing personnel.

11.1.2 A record of the nominal environmental conditions during the test, such as temperature, humidity, and wind conditions.

11.1.3 The test data record(s).

11.1.4 An indication establishing a relationship between at least one time point in each test data record and a corresponding known physical position of the ride or device in the ride cycle. In the case where a known physical position in the ride cycle cannot be established due to the random or non-repeatable nature of the ride, an indication establishing a relationship between at least one time point in each test data record and a corresponding time point in the ride cycle shall be provided.

11.1.5 The results of all field calibration procedures performed as part of the test procedure (see 10.2).

11.1.6 Documentation of the transducer mounting method including the results from any analytical or experimental evaluation of transducer mounting effects on the data channel (see 9.2.1, 12.1.6).

11.1.7 Documentation of transducer mounting location(s) and orientation(s).

11.1.8 Documentation of the measurement coordinate system, including identification of the positive direction along each of the coordinate axes.

11.1.9 A description of each data channel utilized during the test, including but not limited to:

11.1.9.1 Data channel title, engineering units, CFC, and data channel resolution.

11.1.9.2 Documentation regarding the inclusion or exclusion of gravity effects in the zero bias for data channels that are sensitive to gravity.

11.1.10 The manufacturer, model, serial number, and most recent calibration date for all data channel components that are subject to the calibration requirements of this practice.

11.1.11 Documentation of the ride or device operating parameters for each test data record including but not limited to: patron load or ballast weight and brake settings.

12. Standardized Amusement Ride Characterization Test (SARC Test)

12.1 In addition to the general provisions of this practice, a SARC Test shall also conform to the following specifications:

12.1.1 *Testing Ballast Weight:*

12.1.1.1 Those amusement rides or devices where adults are permitted to ride shall be tested with a total ballast weight equivalent to between 145 and 170 lb for each patron location.

12.1.1.2 Those amusement rides or devices that are strictly limited to children shall be tested with a total ballast weight equivalent to between 75 and 100 lb for each patron location.

12.1.2 Triaxial accelerations shall be measured (see 9.2.2).

12.1.3 Each of the three acceleration data channels shall conform to CFC10.

12.1.4 Data channel full scale shall be nominally 10g giving a data channel range of ±10g with a minimum resolution of 0.05g.

12.1.5 *Transducer Location:*

12.1.5.1 *Location—Adult:*

(1) For a ride or device in which patrons ride while seated, the center of seismic mass of the accelerometer (or point center of seismic masses in the case of multiple accelerometers) shall be mounted at a location between 13 and 16 in. (33 and 41 cm) above the seat level and between 3 and 5 in. (8 and 13 cm) fore of the upper torso contact surface or, in the absence of such surface, a plane reasonably approximating the location of the posterior aspect of the patron's upper torso.

(2) For a ride or device in which patrons ride while standing, the center of seismic mass of the accelerometer (or point center of seismic masses in the case of multiple accelerometers) shall be mounted at a location between 45 and 49 in. (114 and 125 cm) above floor level and between 3 and 5 in. (8 and 13 cm) fore of the upper torso contact surface, or in the absence of such a surface a plane reasonably approximating the location of the posterior aspect of the patron's upper torso.

(3) For a ride or device in which patrons ride supine or prone (lying down), the center of seismic mass of the accelerometer (or point center of seismic masses in the case of multiple accelerometers) shall be mounted at a location between 3 and 5 in. (8 and 13 cm) above the upper torso or chest contact surface or, in the absence of such a surface, a plane reasonably approximating the location of the posterior aspect of the patron's upper torso and 45 and 49 in. (114 and 125 cm) superior (as directed along the negative Z axis of the patron's coordinate system) of the foot contact surface or, in the absence of such surface, a plane reasonably approximating the location of the plantar aspect of the feet.

12.1.5.2 *Location—Children:*

(1) For a ride or device in which patrons ride while seated, the center of seismic mass of the accelerometer (or point center of seismic masses in the case of multiple accelerometers) shall be mounted at a location between 11 and 13 in. (28 and 33 cm) above the seat level and between 1 and 3 in. (3 and 8 cm) fore of the upper torso contact surface or, in the absence of such surface, a plane reasonably approximating the location of the posterior aspect of the patron's upper torso

(2) For a ride or device in which patrons ride while standing, the center of seismic mass of the accelerometer (or point center of seismic masses in the case of multiple accelerometers) shall be mounted at a location between 28 and 32 in. (71 and 81 cm) above floor level and between 1 and 3 in. (3 and 8 cm) fore of the upper torso contact surface, or in the absence of such a surface a plane reasonably approximating the location of the posterior aspect of the patron's upper torso.

(3) For a ride or device in which patrons ride supine or prone (lying down), the center of seismic mass of the accelerometer (or point center of seismic masses in the case of multiple accelerometers) shall be mounted at a location between 1 and 3 in. (3 and 8 cm) above the upper torso or chest contact surface or, in the absence of such a surface, a plane reasonably approximating the location of the posterior aspect of the patron's upper torso and 28 and 32 in. (71 and 81 cm) superior (as directed along the negative Z axis of the patron's coordinate system) of the foot contact surface or, in the absence of such surface, a plane reasonably approximating the location of the plantar aspect of the feet.