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Heavy commercial vehicles and buses — Centre of gravity measurements — Axle lift, tilt-table and stable pendulum test methods

Véhicules utilitaires lourds et autobus — Mesure du centre de gravité — Méthode d'essais du plateau incline, levage d'un essieu et pendule stable

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Methods are presented for measuring the location of the centre of gravity of an individual vehicle unit in the horizontal, lateral and vertical planes. Location of the longitudinal and lateral centre of gravity positions are obtained through successive use of wheel or platform scales. Three different methods are described for measurement of the vertical centre of gravity – the axle lift method, the tilt-table method, and the stable pendulum method. The selection of the method to use depends on the facility and resource availability, as well as constraints imposed by the vehicle design. Knowledge of a vehicle unit's centre of gravity supports vehicle modelling work, design validation and planning for other dynamic tests yet to be performed.

Heavy commercial vehicles and buses — Centre of gravity measurements — Axle lift, tilt-table and stable pendulum test methods

1 Scope

This document describes a standard method for measuring a vehicle's longitudinal and lateral (horizontal plane) centre of gravity (CG) positions and three methods for estimating a vehicle's vertical CG position, the axle lift, tilt-table, and stable pendulum methods. It applies to heavy vehicles, that is commercial vehicles and buses as defined in ISO 3833 (trucks and trailers with maximum weight above 3,5 tonnes and buses and articulated buses with maximum weight above 5 tonnes, according to ECE and EC vehicle classification, categories M3, N2, N3, O3 and O4). CG measurements are performed separately for each single unit.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 612, *Road vehicles — Dimensions of motor vehicles and towed vehicles — Terms and definitions*

ISO 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

ISO 15037-2, *Road vehicles — Vehicle dynamics test methods — Part 2: General conditions for heavy vehicles and buses*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855, ISO 15037-2 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
scale
instrument or device used to measure total vehicle, axle, track or individual wheel weights

3.2
crane
device used to lift one end of the test vehicle, with sufficient lift capacity

3.3
load cell
device for measuring force along a single axis

3.4
axle hoist
device used to lift an individual axle with the *crane* (3.2) and safety provisions to prevent the axle from leaving the hoist once lifted

3.5
tilt-table
apparatus for supporting a vehicle on a nominally planar surface and for tilting the vehicle in roll by rotating that surface about an axis nominally parallel to the x-axis of the vehicle

Note 1 to entry: A tilt-table is composed of (1) a single structure supporting all tyres of the vehicle on a contiguous surface, or (2) multiple structures supporting one or more axles on separated, but nominally coplanar surfaces.

3.6
wheel dummy
surrogate solid wheel used to remove tyre compliance

3.7
trip rail
rail or kerb fixed to the *tilt-table* (3.5) surface and oriented longitudinally beside the low-side wheel dummies to prevent the vehicle from sliding sideways

3.8
tilt angle
Φ_T
angle between the ground plane and a vector that is in the plane of the *tilt-table* (3.5) surface and is perpendicular to the tilt axis

3.9
tilt angle variance
differences between the *tilt angles* (3.8) observed at each vehicle axle due to *tilt-table* (3.5) compliance, twist or misalignment of multi-platform tilt-tables

3.10
critical wheel lift
first moment when one or more wheels lifts from the table surface, following which stable roll equilibrium of the vehicle cannot be maintained

3.11
critical tilt angle
Φ_{Tc}
tilt angle at *critical wheel lift* (3.10)

3.12
tilt-table ratio
TTR
tan (Φ_{Tc}), as shown in Formula (1)

$$\mathrm{TTR} = \tan(\Phi_{\mathrm{Tc}}) \quad (1)$$

Note 1 to entry: It can also be expressed as tan (Φ_T) at the occurrence of *critical wheel lift* (3.10).

Note 2 to entry: See Figure 5.

3.13
central axis
axis defined as the intersection of the longitudinal median plane of the vehicle, Xv-Zv, and the ground plane

3.14
stable pendulum
pendulum apparatus for supporting a vehicle on a nominally planar surface where the combined vehicle and pendulum centre of gravity is below the pivot point

3.15
unstable pendulum
pendulum apparatus for supporting a vehicle on a nominally planar surface where the combined vehicle and pendulum centre of gravity is above the pivot point

3.16
platform
nominally planar surface of the pendulum on which the vehicle unit or trailer is parked

3.17
vehicle restraint
means to constrain the vehicle unit or trailer in the longitudinal direction on the pendulum *platform* (3.16)

4 Principles

This document specifies a method to determine the longitudinal and lateral centre of gravity coordinates in the horizontal plane and three common methods to determine the vertical centre of gravity coordinate. The longitudinal and lateral centre of gravity coordinates, x_{CG} and y_{CG}, are determined in the horizontal plane using scales. Individual scales can be used at each wheel or axle location, or the vehicle wheels or axles can be moved across a single scale successively. The vertical centre of gravity coordinate (z_{CG}) is determined using either the axle lift, tilt-table or stable pendulum method.

The accuracy of the vertical centre of gravity measurements is dependent on the vehicle condition during measurement, measurement equipment accuracy and potential movement of heavy sprung or unsprung masses within the vehicle – such as engine and transmission assemblies and suspensions –, during the measurement process. Methods involving tilting the vehicle or lifting the vehicle axles are prone to movement of suspended components. Consequently, the required accuracy of the vertical centre of gravity measurement should be considered when selecting a measurement method. In general, the pendulum method results in less movement of suspended components, and does not require that the suspension be locked-out vertically.

5 Variables

5.1 Reference system

The reference system specified in ISO 15037-2 shall apply.

5.2 Variables to be measured

5.2.1 Variables to be measured for location of x_{CG} and y_{CG} coordinates of centre of gravity in horizontal plane

With the vehicle at rest on the ground plane and prepared with the load condition specified for the test, the following shall be measured and recorded in accordance with the dimensions given in ISO 612 and ISO 8855.

- F_z the total vehicle load (or weight);
- n_a number of axles;
- F_{zi} ith axle load (F_{z1} is the front axle load);
- $F_{zi,left}$ ith axle, left wheel track load;
- $F_{zi,right}$ ith axle, right wheel track load;
- $F_{z,left}$ total left track load;

— $F_{z,right}$ total right track load;

— l vehicle average wheelbase of 2-axle vehicle;

— l_{right} right track wheelbase of 2-axle vehicle;

— l_{left} left track wheelbase of 2-axle vehicle;

— l_{i-1} average axle distance (left and right track) from front axle to axle i;

— b_i i^{th} axle track (b_1 is at the front axle).

5.2.2 Variables to be measured using the axle lift method for location of z_{CG} coordinates

In addition to the relevant variables listed above, measure and record the following.

— F_{zi}' i^{th} axle load after lifting is initiated;

— $F_{zi}'_{,left}$ left track axle load on the i^{th} axle after lifting is initiated;

— $F_{zi}'_{,right}$ right track axle load on the i^{th} axle after lifting is initiated;

— θ vehicle pitch angle change in the X Z plane, relative to the initial orientation on the ground plane before lifting occurs;

— r_{stat} average static loaded radius of all tyres; see Annex A;

— $r_{stat\ i}$ the average static loaded radius on the i^{th} axle; see Annex A.

5.2.3 Variables to be measured using the tilt-table method for location of z_{CG} coordinates

In addition to the relevant variables listed above, measure and record the following.

— l_c longitudinal distance between the contact centres of the two axles contacting the trip rail;

— y_{mi} half-width across wheel dummy trip edges on i^{th} axle;

— $r_{stat,\ dummy}$ average static radius of the wheel dummies;

— Φ_{Tc} critical tilt angle;

— Z_s height of the centre of gravity with the wheel dummies.

NOTE See Figure 7 for a description.

5.2.4 Variables to be measured using the stable pendulum method for location of z_{CG} coordinates

In addition to the relevant variables listed above, measure and record the following.

— h pivot height from the platform surface;

— h_p platform's CG distance below the pivot axis;

— W_p load of the platform including the restraint components;

— W_A applied load;

— θ_p tilt angle of the platform relative to the gravity vector (positive for the front of the vehicle pitched down);

— X longitudinal displacement of the vehicle relative to the platform (positive for forward vehicle displacement);

— h_A vertical distance from the pivot axis to the location of the applied load;

— l_A horizontal distance from the pivot axis to the location of the applied load.

NOTE See Figure 8 for a description.

6 Measuring equipment

The measuring equipment, transducer installation and data processing shall be in accordance with ISO 15037-2.

Typical operating ranges of the variables to be determined for this document are shown in Tables 1 and 2 and in ISO 15037-2.

Table 1 — Variables, typical operating ranges and recommended maximum errors of variables not listed in ISO 15037-2 for the longitudinal and lateral centre of gravity measurements

Variable	Typical operating range	Recommended maximum errors of the combined transducer and recorder system
Vehicle, axle or track load:	Up to 40 000 kg (392 400 N)	0,2 %
Distance:	≤2 000 mm	±1 mm
	>2 000 mm	±0,05 %

Table 2 — Variables, typical operating ranges and recommended maximum errors of variables not listed in ISO 15037-2 for the vertical centre of gravity measurement

Method	Variable	Typical operating range	Recommended maximum errors of the combined transducer and recorder system
All	Suspension air-spring inflation pressure:	500–1 000 kPa	15 kPa
	Vehicle, axle or track load:	Up to 40 000 kg (392 400 N)	0,2 %
	Distance:	≤2 000 mm	±1 mm
		>2 000 mm	±0,02 %
Axle Lift	Angles:	±30°	±0,05°
Tilt-table	Angles:	±60°	±0,1°
	Tilt angle variance:	±0,2°	±0,05°
	Heading angle error:	±1,0°	±0,05°
	Tilt rate:	Up to 0,1°/s	0,2 %
	Lateral deflections:	±50 mm	±1 mm
Stable Pendulum	Angles:	±7°	±0,01°
	Applied mass (weight):	Up to 2 500 kg (24 525 N)	±0,2 %
	Distance X:	±20 mm	±1,0 mm

7 Test conditions

7.1 General

The limits and specifications indicated below shall be maintained during the test. Any deviations shall be identified in the test report.

7.2 Ambient conditions

The surface shall be clean and dry, especially if the test is performed outdoors, and the ambient wind speed is recommended to be less than 1 m/s. Since in certain cases the temperature of vehicle components may influence test results, the ambient temperature shall be reported.

7.3 Test surface

The test surface, when applicable, should be in accordance with ISO 15037-2 and the surface should be hard enough to avoid surface deformation when measuring the vehicle.

7.4 Test vehicle

The load condition shall be reported as described in ISO 15037-2. Tyre pressures and the suspension setting (if applicable) shall be recorded.

On vehicles with multiple adjustable seats or other device such as beds, adjust the items to a mid-travel position (longitudinal and vertical) and adjust the seat back torso angle to the manufacturers' designated specification or as close as possible to 15°. The positions shall be reported.

On vehicles with steering wheel reach and rake, the position shall be reported.

7.5 Operating and other liquids

The fuel tanks shall be completely full or empty, including the urea tanks. Fuel motion within an unfilled fuel tank can have an adverse effect on the results. If the displacement of other liquids carried on the vehicle (operating and otherwise), such as engine oil, is expected to influence the results, precautions should be taken to fill the fluid tanks, drain the fluids or note the potential issue. Tank conditions (empty or full) and locations shall be reported. Occurrences of leaking fluid when the vehicle is inclined should be noted.

7.6 Loading conditions, suspension and mechanical parts

Vehicle payload shall be held in place to avoid displacement due to inclination of the vehicle.

If the vehicle has a suspended cab or semi-suspended cab, the cab shall be locked at its standard height when the vehicle is in a horizontal plane with no driver in the cab. Once the vehicle payload is set, the wheel suspension shall be locked or constrained to avoid deflection during vehicle inclination or pitching. Other components with flexible mounting may need to be constrained as well, if deflection will adversely influence the results. It may not be necessary to lock out these components if the stable pendulum method is used to measure the vertical centre of gravity.

Immediately prior to each test event, all self-regulating suspensions shall be adjusted such that they are at the proper ride height or, in the case of the suspensions for certain auxiliary axles, at the prescribed inflation pressure. The initial ride height of each suspension shall be reported.

When lifting or inclining the vehicle during the axle lift method test, the gearbox shall be in neutral, any lockable differential shall be released, and the parking-brake shall be released with no longitudinal constraints applied. Any steerable wheel shall be steered straight ahead.

