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GB/T 13441.4-2012

Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems

机械振动与冲击 人体暴露于全身振动的评价 第4部分：振动和旋转运动对固定导轨运输系统中的乘客及乘务员舒适影响的评价指南

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1 Scope

This part of GB/T 13441 is a specific application of GB/T 13441.1, namely a guide to evaluating the effect of mechanical vibration on the comfort of passengers and crew in fixed-guideway transport systems. It is intended for organizations that purchase, specify technical conditions for, or operate fixed-guideway systems, and it helps them relate the design of the system and its other characteristics to the comfort of passengers and crew. The guide establishes a method of evaluating relative comfort between systems, not an absolute grade of comfort.

The part applies to healthy people exposed to translational vibration along the x, y and z axes and to rotational vibration about the three axes centred on the human body. It gives guidance for assessing comfort by using, as a motion function, the motion of the body generated along and about the coordinate axes of the vehicle. It does not apply to high-magnitude single transient motions that can cause injury, such as the impact of a vehicle accident or of longitudinal slack action in a train, nor to high-magnitude vibration that could affect health.

The fixed-guideway passenger transport systems covered include track systems, both heavy rail and light rail, magnetic levitation (MAGLEV) systems and rubber-tyred metro systems, together with the various transport systems that rely on the body tilting characteristics named above to offset lateral acceleration when passing through curves.

The part gives guidance on ultra-low-frequency vertical acceleration in the range 0.1 Hz to 0.5 Hz, produced by vertical forces, that can lead to motion sickness. Such vertical forces can arise from the combined action of transition curves, cant and car body tilting. The part does not give guidance on the comfort effect of ultra-low-frequency acceleration below 0.5 Hz produced by lateral or longitudinal forces; acceleration of that kind arises from the geometry of the guideway, that is from its horizontal alignment and its cant.

The part gives evaluation guidance on ride comfort based only on the motion environment.

2 Normative references

The following documents are indispensable for the application of the document; for dated references only the edition cited applies, and for undated references the latest edition, including all amendments, applies.

IEC 61260 Electroacoustics-Octave-band and fractional-octave-band filters.

GB/T 13441.1-2007 Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements (ISO 2631-1:1997, IDT).

3 Matters needing special consideration in fixed-guideway transport systems

Fixed-guideway systems can produce marked repeated motion and vibration that affects passenger comfort. Among these motions, the concern is with translational motion and rotational motion along and about any one of the three mutually orthogonal coordinate axes of the vehicle. Vertical, lateral and roll motions have been shown to have an important effect on the comfort of passengers in rail vehicles. Lateral and longitudinal motions have the greatest effect on standing passengers or crew.

Factors that bear on the comfort felt by passengers, including noise level, visual stimulus, temperature and humidity, interact with vibration; when vehicle motion test results are used to assess comfort, the effect of these non-motion factors is to be taken into account. A relationship has already been found between noise and the ride comfort assessment of passengers in rail vehicles.

The coordinate system centred on the human body cannot fully express the relation between comfort and motion in a fixed-guideway system, because a passenger may be standing, sitting or lying in various positions relative to the car body. In practice a fuller picture of the comfort environment produced by vehicle motion can be obtained by measuring at the contact surface between seat and body. When measurement is made at the seat-to-body contact surface, the guidance on the basic body-centred coordinate system shown in Figure 1 of GB/T 13441.1-2007 is to be used.

Although measurement at the seat-to-body contact surface is the first choice of GB/T 13441.1-2007, that method may not always suit the evaluation of fixed-guideway systems. The inherent uncertainty produced by test subjects changing posture and moving of their own accord casts some doubt on such measurement results. The ride environment of a fixed-guideway system is formed jointly by the guideway, the vehicle suspension, the car body and the seat or berth, and seats and berths are not permanent parts of the vehicle: they may be replaced several times during the life of the vehicle.

The activity of passengers makes the comfort assessment more complex, since it is affected by their expectations and by the duration of the journey. Journey duration may vary from a few minutes to several days, and passengers expect to take part in a wide range of activities including walking, reading, writing, typing, eating, drinking and sleeping. Certain motions of the train not only hinder some of these activities but also increase the likelihood of motion sickness for activities that need visual concentration, reading and writing above all.

For a meaningful comparison between vehicles or between systems, the suspension conditions of the vehicle under test and the state of the track or guideway section used are to be stated. In general it is advisable to test over representative straight and curved track sections, and the test section should include track or guideway of the various qualities the vehicle is meant to run on. In the same way, vehicles fitted with new wheels and vehicles whose wheels have worn to the maintenance limit should both be tested.

Tests should be made both with the vehicle empty and with it fully loaded, and may also be made at other load conditions. The position of the test vehicle in the train formation, and in some cases the direction of running, affect the test result. The vehicles next to the test vehicle also affect the test. It is therefore advisable to record and report the position of the test vehicle in the formation and its direction of running.

4 Motion characteristics of fixed-guideway vehicles

The motion of a fixed-guideway vehicle can be characterized by the following: a) semi-random translational acceleration, all of it along the three coordinate axes, and semi-random angular acceleration about the three coordinate axes, caused by defects of the wheel-rail contact surfaces, errors in the track centre line and similar sources; b) more or less periodic motion caused by instability such as hunting, by suspension motion, by long-wave track irregularity, by the periodic spacing of rail joints and by turnouts; c) quasi-static acceleration amplitudes along the lateral and vertical axes caused by longitudinal and lateral inclination, that is cant, together with roll and yaw motion, and quasi-static acceleration amplitudes along the longitudinal axis caused by vehicle acceleration and braking; d) sudden motion caused by a major defect of the track or of a turnout, or a quasi-static change of level, that is a jolt, caused by a change of curve radius with or without a transition curve.

The frequency ranges of motion generally held to affect ride comfort in rail vehicles are: 0.1 Hz to 2 Hz for transition curves in roll; 0.5 Hz to 10 Hz for the lateral and longitudinal directions; and 0.5 Hz to 20 Hz for the vertical direction.

For very high speed vehicles, at 250 km/h and above, and for tilting trains, vertical acceleration is produced in the frequency range 0.1 Hz to 0.5 Hz. Vertical acceleration of such low frequency can induce motion sickness. Annex D of GB/T 13441.1-2007 gives guidance on a method of calculating the motion sickness dose value from acceleration in that frequency range.

Two kinds of roll motion can occur: relatively high-amplitude, ultra-low-frequency roll motion set off on entering or leaving the canted section of a curved track or guideway; and repeated lateral swaying motion produced by the interaction of the suspension and the guideway.

For systems with a large amount of guideway cant, with a tilting suspension device, or with both, it is advisable to consider the roll angle and the roll velocity, that is the rate of roll, when assessing the effect of motion on comfort.

A sustained tilt angle arises when transition curves are used, that is curves entering and returning through a transition section. When such a sustained tilt builds up gradually and then stays constant, it does not make passengers uncomfortable. Repeated exposure to a high roll rate that reaches such a roll angle quickly and returns quickly to the normal position can, however, cause motion sickness, and that high roll rate occurs when transition curves are used. A transition curve of a certain length is therefore a potential cause of passenger discomfort and motion sickness when the train runs at very high speed.

5 Measurement

The guideway, the wheels, the suspension, the car body structure and the interior fittings, that is the seats and berths, all affect how passengers and crew perceive vibration.

When the effect of the seat or berth on comfort is the first concern, measurement at the seat-to-body or berth-to-body contact surface becomes important. These contact surfaces are the direct points of contact between the car body structure and the human body; they support and guide the body and transmit its weight to the car body itself, as shown in Table 1. For evaluating the overall vibration value for standing, seated and recumbent people, measurement should be made at the human interfaces given in Table 1. A note adds that in some cases it is practical to measure for a seated passenger at the headrest-to-neck interface and at the armrest-to-forearm interface, and likewise practical to measure for a recumbent passenger at the berth-to-leg interface.

Table 1, headed Human interfaces, carries two columns, posture and interface, and three rows. For the standing posture the interface is floor to feet. For the seated posture three interfaces are listed: the seat pan, the seat back, and floor to feet. For the recumbent posture the interface is the supporting surface for the pelvis, the back and the head.

Over the service life of the vehicle and the guideway, the fixed equipment, that is seats and berths, usually has to be replaced several times. Measurement on the vehicle structure is more meaningful than measurement at these interfaces, so measurement on a rigid part of the vehicle may be more suitable, as stated in Note 1 to 5.3.1 of GB/T 13441.1-2007. For measurement at points on the vehicle structure it is advisable to use the following reference coordinate system: the z axis vertical, orthogonal to the floor, positive upwards and negative downwards; the x axis longitudinal, along the direction of running, positive