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Tresenje celotnega telesa – Smernice za zmanjšanje tveganja zaradi vibracij – 1. del: Inženirske metode pri načrtovanju strojev

Whole-body vibration - Guidelines for vibration hazards reduction - Part 1: Engineering methods by design of machinery

Ganzkörper-Schwingungen - Leitfaden zur Verringerung der Gefährdung durch Schwingungen - Teil 1: Technische Maßnahmen durch die Gestaltung von Maschinen

Vibrations globales du corps - Guide pour la réduction des risques de vibrations - Partie 1: Mesures techniques lors de la conception des machines

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Foreword

This Technical Report (CEN/TR 15172-1:2005) has been prepared by Technical Committee CEN/TC 231 “Mechanical vibration and shock”, the secretariat of which is held by DIN.

CEN/TR 15172 consists of the following parts:

CEN/TR 15172-1, *Whole-body vibration — Guidelines for vibration hazards reduction — Part 1: Engineering methods by design of machinery*

CEN/TR 15172-2, *Whole-body vibration — Guidelines for vibration hazards reduction — Part 2: Management measures at the workplace*

Introduction

This Technical Report deals with engineering methods for design of machinery transmitting vibration to the human body. Guidance on management measures at the workplace is given in CEN/TR 15172-2.

Significant whole-body vibration is mainly related to operators of mobile machinery. Mobile machinery transmits vibration and shock from the seat for seated operators, from the floor for standing operators, which may cause adverse health effects, primarily damage to the spine. The effects of vibration depend on its frequency, direction, intensity, presence of shocks and on the exposure time. They also depend on the operator's posture. It is important to understand that the design and manufacture of mobile machinery is complex, requiring extensive technical background.

The EC Directive 98/37/EC on the approximation of the laws of the member states relating to machinery (Machinery Directive), amended by Directive 98/79/EC, requires that the machinery is so designed and constructed that risks resulting from vibration produced by the machinery are reduced to the lowest level, taking account of technical progress and the availability of means of reducing vibration, in particular at source. Limiting vibration by design is one of the measures that EN ISO 12100-2 suggests machine manufacturers and designers should consider as part of a strategy to achieve safety by design of machinery in conformity with European Legislation.

The reduction of vibration by design of machinery can make an important contribution to the effective protection of people at work from the harmful effects of vibration. In practical situations, however, a combination of engineering measures and management measures may be necessary.

1 Scope

This Technical Report provides best practices and methods available for limiting the effects of mechanical whole-body vibration on operators' positions. The guidelines given outline practical ways in which whole-body vibration hazards associated with mobile machinery can be reduced by machinery design. The Technical Report covers four important aspects of the reduction of the effects arising from exposure to hazardous machinery vibration:

a) identification of main sources and operational modes producing vibration that might be hazardous to health and of additional factors worsening the adverse health effects of vibration on the operators;

b) reduction of vibration magnitudes at source;

c) reduction of transmission of vibration from source to the operator;

d) ergonomic adaptation of operators' position: posture, range of vision.

This Technical Report does not provide universal or detailed technical solutions but only a review of engineering methods available. It is not concerned with hand-arm vibration which is covered by CR 1030-1.

This Technical Report is primarily intended as a guideline for people involved in purchasing, using, supplying, marketing or inspecting mobile machinery. It is also intended to be a guidance for writers of type C standards for specific types of machinery.

2 Identification of main sources and operational modes producing vibration that might be hazardous to health

2.1 Identification of main sources and operational modes

The machine manufacturer should make a careful investigation of all possible causes of vibration and shock connected with the full range of likely use of the machinery. In case the machinery is used with tools, the investigation should include the range of tools likely to be used with the machine.

Internal sources of vibration in mobile machinery are engines, hydraulic devices and transmission.

Normally, the engine is not a problem unless it runs at low speed and has only a small number of cylinders. Generally, the engine may be a problem in older, poorly maintained machines and in machines where the user has made changes in the original construction.

Some machinery categories, e.g. vibratory rollers, include intentional vibrating sources. Machinery may also use vibrating attachment, e.g. separators, rotary snow-ploughs, street-sweeping machines, road milling machines, refuse collection lorries. Rough braking and handling of gears can cause large vibration and shocks.

The major source of vibration affecting operators of mobile machinery is the contact between wheels and ground at travelling. The severity is determined by the combination of ground surface, machine dynamics and travelling speed.

For machinery using tools, the contact between the tool and the material, e.g. in digging, rock drilling, loading, compaction, is of vital importance. The vibration magnitude depends on the characteristics of the material and the operator's skill.

Examples where the tools can be the dominant source of vibration are excavators using breakers.

In case of using a trailer, the design of the connection of the trailer to the machine (e.g. truck, lorry) is important as is the position of the centre of gravity of the trailer.

Liquids cause vibration when sloshing in tanks. Tanks can be divided into smaller rooms, which will minimise the vibration.

Some information on methodologies for identification of vibration and shock during various operational modes can be found in EN 1032 and EN 14253.

2.2 Factors that can combine with vibration to increase the likelihood of injury

It is probably the combination of the stresses from poor position and vibration that causes back pain. The machinery manufacturer should make a careful investigation of all possible causes which might force the operator to adopt poor posture.

The ergonomic design should support a driving posture that minimises the adverse effects of the vibration transmitted to the body (primarily to the spine). An upright driving position is important.

Outside visibility always comes first. Even if it is detrimental to his posture, an operator will compensate to overcome the lack of good visibility essential for safe machine operation. Driving a counterbalance truck with a high load, cutting the grass with a tractor along the merge of a road are examples where the operators might bend forwards or backwards or twist the body in order to increase the visibility at travelling or operating of equipment.

When the vertical seat adjustment is insufficient, some operators can have difficulty to reach the floor pan or pedals with the feet. In fork lift trucks tall operators have to drive in bent position in order to avoid the head to get in contact with the overhead guard.

On some vehicles the operator's legs cannot slip easily under the steering wheel. When this is the case, the operator might push his seat back to allow his thigh room to move and as a result he has to lean forward to operate the machine controls and steering wheel.

The adverse health effects of vibration can increase when the machine is operated on slopes and side slopes due to effects on operator's posture, on efficiency of cab and seat suspension.

Jumping from machines could cause significant shock loads to the body. To minimise this risk, a well designed machine access system (including suitably placed hand holds and slip resistant steps) should be provided and the operator should be encouraged to use the access system instead of jumping from the machine. Machine specific standards for access systems should be used, such as EN ISO 2867 for earth-moving machines or EN 1553 agricultural machinery. When no machine specific access system standard is available, general guidelines for access systems can be obtained from the EN ISO 14122 series.

3 Reduction of vibration at source

3.1 Travelling on uneven surfaces

The vibration affecting the operator when travelling depends on the mechanical design of the machine. It also depends on the ergonomic design (e.g. visibility) that can help the operator to avoid excessive vibration, e.g. by choosing speed and route around obstacles.

It should be observed that also small obstacles may lead to high vibration levels for machines with small-size wheels, hard tyres, a short wheelbase or less suspension.

The vibration and shock caused by the contact between the machinery and the ground when travelling is affected by the design and dimensions of the wheels. Designers should aim at a low centre of gravity, located close to the cross point of the diagonal lines between the wheels. In some cases the centre of gravity can move when travelling, e.g. machinery carrying a tool such as a suspended boom. This movement should be taken into account.

Working equipment and tools mounted to the machinery might cause excessive vibration at travelling due to change of the centre of gravity. An example of avoiding this is the use of special suspension devices, e.g. hydraulic accumulators for boom suspension in earth-moving machinery. The manufacturer should give information on limitation of tools and the effects on the vibration by the use of tools.

3.2 Operating of working equipment (tools)

Examples of working equipment are:

- buckets of excavators,
- ploughs, balers or powered cultivators;
- cranes and processors (cutting devices) of forestry machines;
- grading devices of graders;
- drilling devices of mining machines;
- milling devices of road milling machines.

Generally, soft movements should be aimed at in the design of working equipment and its integration in the machine. Vibration should not be transmitted from the tool to the operator's position.

Hydraulic functions should be carefully adapted to provide soft operation.

Linkages should be correctly balanced and excessive play avoided. Accessories and loads can change the centre of gravity, changing the vibration characteristics when moving.

The controls of the tools should be placed so that the operator will maintain an upright position and avoid unnecessary twisting of the body when using the tools.

3.3 Information from the manufacturer on the use of tools and accessories

One important factor is to provide the right tool for the job. The machinery manufacturer should give good guidance on what tools to use and how to operate the tools in order to minimise the vibration without losing efficiency. Also the tool maintenance instructions are important.

The manufacturer should provide information on limitation of application of tools and the effects on vibration by use of tools. The manufacturer should also provide information on limitation of slope, limitation of loads, speed, etc.

Often problems occur when the machine and tool have been produced by different manufacturers.

Manufacturers should provide instructions on how accessories and loads should be carried in specific operating modes to minimise vibration, e.g. for earth-moving machinery, the boom should be raised when travelling (use of accumulators).

3.4 Vibrating tools mounted to the machinery

If a machine is equipped with optional vibrating hydraulic tools, e.g. hydraulic hammers, cutter crushers or screening buckets, this could contribute to the vibration of the operator. As a minimum, the operating frequency and level of excitation force of the tool needs to be known and the influence from this tool should be evaluated together with the vibration isolation systems of the main machine in order to minimise the vibration exposure of the operator.

The tools may be boom mounted or three-point linked.

In the case of machinery including vibration exciters, e.g. vibratory rollers, it is important that the frequency selected for the excitation is as high as feasible with regard to the work efficiency in order to enable an efficient isolation of the operator from the source. It is also important to avoid a conflict between this frequency and its harmonics and the resonance frequencies of the machine structure.

3.5 Engine

Vibration produced by the engine is unlikely to be of a magnitude that could cause a health risk, presumed that the engine is well balanced and resiliently mounted to the structure. For one-cylinder reciprocating engines, where balancing is not normally feasible, extra care needs to be taken in the mounting of the engine. It is of primary importance to avoid with good margins a coincidence between n times the rotational speed of the engine and resonance frequencies of the engine suspension and of the engine mounting structure (n is an integer).

4 Reduction of transmission of vibration from source to the operator

4.1 General

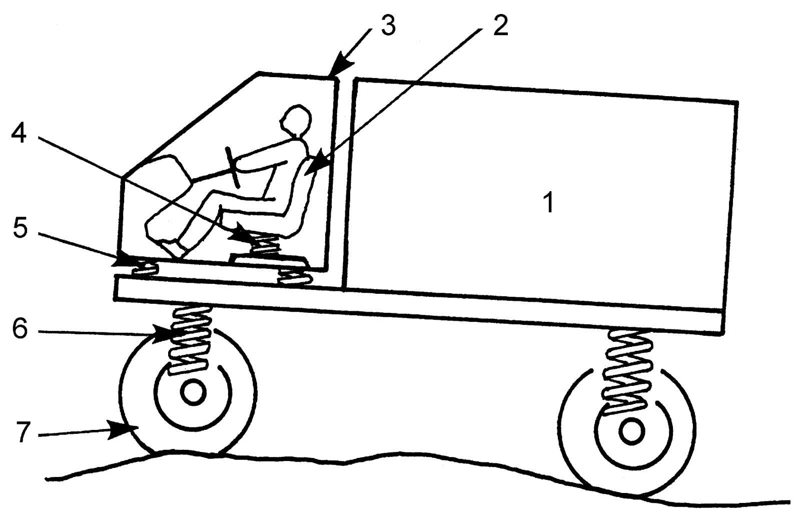
Reduction of transmission of vibration from source to the operator often includes use of resilient mounts, either by separating the source of vibration (e.g. engine) from the machine structure or by separating the operator from the vibration source or vibrating structure (vibration and shock isolation of wheels, chassis, operator's cab, seat).

Methods for vibration and shock isolation are well described in the literature and handbooks. It is important that the designer of resilient suspension systems and their integration in the machine has good knowledge of structural dynamics. The designer needs to know how to optimise the system with regard to resonance frequencies, internal damping in the isolating elements, and location and directivity of elements in relation to the centre of gravity of the part to be isolated.

Some general considerations in selection of vibration and shock isolating devices can be found in EN 1299.

Transmission of vibration and shocks from the contact between the ground and tyres to the operator can be reduced by means of vibration isolation elements (resilient suspension systems) positioned at different key points (see Figure 1):

- Tyres;
- wheels and chassis (vehicle body);
- cab;
- seat.



Key

1 vehicle body

2 seat

3 cab

4 seat suspension

5 cab suspension

6 body suspension

7 tyres

Figure 1 — Schematic presentation of possible suspensions

When resilient suspension systems are designed and selected, it is important that prevention from both shock and vibration is taken into account. Ideally, a resilient suspension should be designed so that its highest cut-off frequency is significantly less than the dominant input frequency. Suspension travel should be sufficient to prevent bottoming or topping on end-stops. The lower the input and the cut-off frequency, the larger the required travel. A compromise should be developed for the specific machine between the capacity of reducing long-term low-level vibration and occasionally occurring high-level vibration and shock. Internal damping in the suspension system has a positive effect on vibration transmission at the resonance frequency of the suspension system, but insignificant effect on the reduction of occasional shocks or bumps.

Use of several resilient suspension systems in a suspension chain, e.g. simultaneous use of soft pneumatic tyres, resilient chassis suspension, resilient cab suspension and resilient seat suspension, requires high technical skill, due to the complex interaction of the suspension systems. It is also important that the characteristics of the suspension systems do not change over long periods of time (this is especially a problem for systems based on organic materials). The manufacturer should provide recommendations on replacement of the suspension system elements. It is important that such recommendations are followed.

Basic concepts of suspension systems are given in Annex A.

4.2 Wheel size and tyres

Tyres are normally selected according to their rolling resistance, grip, stability, cost, resistance to collision damage, etc.

The machinery manufacturer should carefully investigate the vibration generation characteristics of the tyres and recommend tyres and inflating pressures that minimise the vibration in the particular machine. Information should be provided on the appropriate selection of tyres for different use of the machine.

Small-dimension wheels will cause excessive vibration also when travelling over small ground irregularities. It is therefore important that the wheel size is selected for the typical travelling conditions of the machine.